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# PLASTIC SHEET FORMING

*by*

ROBERT L. BUTZKO
*The Auto-Vac Company*
*Bridgeport, Conn.*

REINHOLD PUBLISHING CORPORATION
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# Reinhold Plastics Applications Series

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Many factors are involved in the determination of the optimum application of a plastic and the correct application in a very real sense determines the true worth of a material. The plastic best to use for a given product must not only fill the required physical specifications, but it must also be competitively priced.

Realizing the importance of correct application in the whole gamut of plastics activity, the Reinhold Publishing Corporation, early in 1956, decided to publish a series of short books emphasizing the applications of the various types of commercial materials of the plastics industry—each book to cover one type of material or one process. The present volume by Robert L. Butzko is the fourth of this series. Those already published are the volumes on "Polyethylene," "Polyurethanes," and "Polyamides." Others now in preparation cover the following subjects: acrylics, cellulosics, epoxies, fluorocarbons, laminates, polystyrenes, gum plastics, silicones, vinyls and welding of plastics.

The series is semi-technical—that is, one does not need to be a chemist to understand the various volumes. The authors have kept in mind as probable readers such industrial men and women as: design engineers, equipment manufacturers, producers of packages, manufacturers of packaging machinery, students at technical schools and, of course, those in the plastics industry—material manufacturers, molders, extruders, fabricators.

In addition to the above, it is hoped that each title will appeal to readers in specialized categories. Plastics from which fibers are made may be of interest to tire and fabric manufacturers. A book such as the one on vinyls, which materials are favorable for production of sheets, may have value for manufacturers of handbags and luggage. Similarly, other titles may appeal to manufacturers of paints, recorder tapes, upholstery, plywood and furniture.

With this program now well launched, it is with enthusiasm that this fourth book of the series is presented.

HERBERT R. SIMONDS, *Editor*

# Titles in Preparation

Acrylic Resins, *Nathaniel C. Ratner*

Cellulosics, *Walter Paist*

Epoxy Resins, *Irving Skeist*

Fluorocarbons, *Merritt A. Rudner*

Gum Plastics, *M. Stafford Thompson*

Laminates, *Dan Duffin and Charles Nerzig*

Polystyrene, *Harold Hartong*

Silicones, *F. M. Lewis and R. N. Meals*

Vinyl Resins, *W. Mayo Smith*

Welding of Plastics, *J. A. Neumann and F. J. Bockhoff*

# PREFACE

With the great advance in recent years in the use of plastic products made by the sheet forming process, there has been an increasing demand for information on this subject. This book was written to fill a need in the industry for a handy reference to be used by those contemplating entering the sheet forming industry as well as by those seeking to increase their knowledge of this new process. It provides an introduction to plastic sheet forming for the engineer and designer plus an explanation of the various techniques of forming for the manufacturing technicians.

Some of the information may seem elementary to those engaged in the field. However, the author felt that this is necessary so that the non-technical reader may be able to evaluate the potentials of the industry according to his own needs. This book is not intended to provide technical answers to all the problems confronting the sheet forming industry, but rather to bring all the scattered information in the field together so that it may be useful to all. However, charts and tables not previously available have been compiled for those in the field to aid in the development and manufacture of plastic products.

It is hoped that the reader will understand that the illustrations and descriptions of the various products and equipment are representative of the industry and by no means comprise a complete listing.

The author wishes to thank the many individuals and companies who have generously furnished information for use in compiling this book.

ROBERT L. BUTZKO

Bridgeport, Conn.
January 1958

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# 1. INTRODUCTION

One of the best success stories of the present era is the rapid growth of that stepchild phase of the booming plastics industry known as plastic sheet forming, vacuum forming or thermoforming. This process, which shapes a plastic product by applying generally air pressure or vacuum to a heat-softened sheet, was not too well known up to 1950.

It is doubtful if there were fifty manufacturers forming thermoplastic sheet plastics at that time, yet it is the oldest plastic process in the country. Sheets of proxolin, the first thermoplastic sheets, were formed as long as forty years ago. Patents were issued as far back as 1896 for machinery to form thermoplastic sheet. Parts for the early horseless carriages were formed from thermoplastic sheet.

Long before Dr. Leo Baekeland's developments in 1909, which is generally considered the start of the plastics industry in this country, a thriving business already existed in thermoplastic sheet. In 1846 Schonlein discovered nitrocellulose in Basle, Switzerland. However, John Wesley Hyatt of this country (noted for his development of roller bearings) was given chief credit for producing in 1868 the commercial plastic called cellulose nitrate. One of its forms was known as "Celluloid" and in those days it was hailed as a substitute for ivory. Even today billiard balls, eyeglass frames, and ping-pong balls are still fabricated from this material.

In 1870 the Albany Dental Plate Company was organized to handle sales and production of "Celluloid," which progressed so rapidly that a second company was formed called the Celluloid Manufacturing Company. This company, which later moved to Newark, N.J., is considered the real pioneer of this plastic industry.

For many years "Celluloid" was the mainstay of the plastics industry. Cast in heavy blocks, it was sliced into sheets on a planer, after which it had to be cured in drying houses for two to three months. All the original movie film was made of this material by a similar casting procedure. However its dangerous explosive and flammable nature caused investigators to search for new materials. Cellulose acetate was originally developed for photograph safety film in 1912; however, it was the middle 1920's before sheets became generally available.

In the 1930's materials came faster. Acrylics made streamlined canopies, windows and radar housings possible, and were used in our aircraft in World War II.

Polystyrene was developed in 1939; it is a low-cost rigid material, and is a mainstay of the present sheet-forming field. Ethyl cellulose, polyethylene, the vinyls, and cellulose acetate butyrate followed quickly. Yet sheet forming lagged in the middle 1940's, and there were even fewer fabricators than in previous years.

With this wonderful start why had it taken all these years for this process to attain its rightful place in the plastics industry? For many years the technique of plastic forming required highly skilled artisans with considerable know-how. Since there was no equipment available for this process, each fabricator had to construct his own machine or adapt equipment from some other industry. Such equipment was crude and had to be tailored for each new job.

After heating in home-made ovens, the heated sheet was laboriously carried to the forming press for the subsequent operations. Controls and timers were virtually unheard of, and production was slow and expensive. It wasn't until 1950 that a machine especially for this process became commercially available. With heating and forming in one machine, and with time-controlled operations, economical production became possible.

Today, machines are highly automatic and precisely controlled. Sheet feeding and roll feeding are available in various sizes and of specialized construction for the many different fields now using sheet forming.

With the availability of these machines new products were possible and new plastics were developed. It is estimated that there are over 1500 machines in use today, turning out 85 million pounds of plastics products a year.

# 2. APPLICATIONS OF SHEET FORMING

To list the many thousands of products now manufactured by the sheet-forming technique is an impossibility due to the rapidly expanding nature of this field. Many plastics products are now possible which were not feasible by previous methods. The chief factors in this expansion are low capital investment, low die cost, wide choice of materials to work from, and low unit cost. Many more materials are available in sheet forming than in any other plastics field. Thicknesses of material from .001 to ⅜ inch are standard. Since the basic plastic sheet is flat before forming many decorative finishes or designs may be applied by various production methods and will be retained in the final formed sheet. Embossed leatherette grains, metalized, flocked, and pre-decorative surfaces can be formed in either a soft flexible material or a hard rigid plastic.

One of the most widely used techniques is that of predecoration. In this process the flat sheet is printed or silkscreened with as many colors as desired. The pattern is distorted so that when formed the colors will fall into the exact place on a deeply formed part. This technique alone has made many products possible in the display and decorative field.

In general, sheet forming has created its own new products instead of replacing products made of other materials or by other processes. It is true that many products are improved versions of those made from wood or metal but the creation of new product fields is a big factor in sheet forming.

It is important to realize that many plastic products cannot be produced by sheet forming and that other products cannot be economically produced by this method. A good understanding of sheet forming products is necessary therefore as a guide for plastics applications. The applications of plastic products which follow are arbitrary and represent the major products to date. Once the techniques of sheet forming have been mastered it is easy to see how these can be applied to many other products.

## Appliances

One of the largest users of sheet-formed parts is the appliance industry. While plastics have been used in the appliance industry for many years, sheet forming is relatively new, yet despite this it is growing by leaps and bounds. Parts presently made by the sheet-forming process are as follows:

Refrigerator door liners
Refrigerator breaker strips
Freezer door compartments
Drip pans
Defroster trays
Washing machine lids
Clock faces
TV masks

While it is almost impossible to list all the products, the above items alone use many hundreds of thousands of pounds of plastic annually.

One of the most natural products developed by sheet forming is the refrigerator door liner. Previous to sheet forming, the door liners were made of porcelainized metal or painted fiberboard. Designs were limited to shallow depressions, and there were no shelves or compartments on the interior of the door. Designers desired the "built-in look" not only for beauty but also for the utility of the added space. Successful injection-molded door liners were produced by injection machines costing from $150,000 to $300,000. Molds cost $25,000 and upward. The first parts fabricated from plastic sheet were simple and were produced on a machine costing under $10,000, with a mold cost of approximately $1,000. The first results were not entirely satisfactory since the sheet had a dull finish and once stained it was hard to clean.

This problem was solved by the development of a styrene copolymer sheet, with an oriented styrene film approximately .001 to .002 inch thick laminated to the top of it at the time

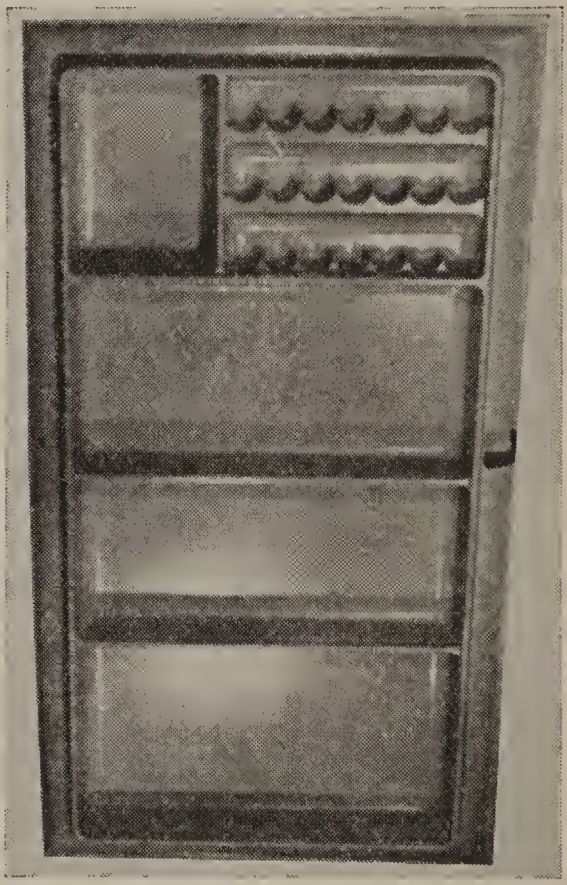

Figure 2–1. A typical refrigerator door liner made of .080 or .100 in. styrene copolymer with high gloss finish. This part weighs from 4 to 6 pounds. Egg compartment at upper right is a complex unit, typical of this type of design. Formerly made of metal or fiberboard, these liners have been replaced by sheet forming almost 100 per cent because of the more complex shapes possible. This type of liner gives added valuable space to the refrigerator.

of manufacturing. When formed it produced a highly lustrous part easily cleaned. Present trends have also developed a styrene copolymer sheet with a glossy surface without using laminated film. Both of the above materials are now used.

With sheet forming it was now possible to make intricate shapes not previously feasible, thus the present refrigerator door has compartments for frozen foods, butter, and eggs—all formed in one piece. These doors are durable and are not affected by normal refrigerator temperatures. It is estimated that practically all consumer refrigerators now being produced have sheet-formed door liners.

In the refrigerator itself the freezer door compartment presented a slightly different problem. In order to achieve proper insulation the freezer door is made of two pieces having an internal and external shell. When these two parts are cemented together the resulting area space provides sufficient insulation for normal use. If additional insulation is required a block of "Styrofoam" is placed between the two parts prior to cementing. Metal inserts with threads are placed between the two pieces for attaching the hardware. In some models of the two-door type refrigerator the breaker strip or the strip which surrounds the edge of the refrigerator compartment is vacuum formed. Drip pans and defroster trays are quite simple parts used in the refrigerator industry.

One company manufacturing an apartment-size washing machine has a vacuum-formed lid which, when folded back on a hinge, provides adequate space for the clothes prior to washing. This has proved very economical and also rugged enough to take the abuse of every-day use.

One of the very first applications of sheet forming was encountered in the television industry where the mask or the area directly around the picture tube employed sheet-formed plastic. Metal was formerly used here but the sheet-formed plastic gave satisfactory performance and since it was easily tooled it gradually replaced the metal mask. One company using a translucent mask turned to a sheet-formed mask because of its even light distribution.

Formed clock faces and dials are one of the newer trends since highly decorative faces can be made with either metalized raised letters or with deep drawn faces. These parts are highly efficient and give lasting performance.

Present appliance trends indicate that soon the entire interior of the refrigerator will be sheet formed, replacing porcelainized metal. Not only will this be economical but greater beauty of color will also be possible. With the current trend in color there are no problems if sheet forming is employed since any color may be added to the basic material and scratches or nicks will not show up as they would on a painted or porcelainized surface.

## Automotive Industry

No industry in the United States is more highly competitive than the automotive industry. New models are a "must" every year and modern trends in safety, comfort, and style must be more advanced in each model. Sheet forming has provided the automotive designer with a tool which will produce beautiful wear-resistant parts with low cost and quick tooling.

More economical than other currently used materials, the sheet-formed parts at the present time are mainly used for interior trim, although utility parts are also made. If the present trend continues, the entire interior of the car, including ceiling and floor coverings, seats, side panels and instrument panels will all be sheet formed in the near future. At the present time the following parts are sheet formed:

Padded instrument panel cover
Safety sunshields
Headliners

Door and side panel trim
Arm rests
Seat kick pads
Compartment liners
Interior covers

Also manufactured experimentally, and in some cases produced in limited quantity, are the following:

Trunk liners
Complete seat and back
Floor covering
Rear seat backing
Complete instrument panel

The materials used for the interior trim usually have a design or embossed surface similar to tooled leather, although some have complete embossed designs of some depth. Designs are easily changed from model to model and any color can be obtained. The materials now used for automotive parts are:

Unsupported vinyl
Supported vinyl with cotton
 and/or rayon backing
Styrene blend for rigid parts
Metalized "Mylar"

In order to sell automobiles today you must be able to satisfy the feminine taste. Formerly, the interiors of cars were made from leathers and fabrics, generally considered inferior to the materials which are used today. The modern woman demands not only that the interior be a thing of beauty, but it must also have a good feel in hot and cold weather. The interior must be resistant to normal stain and it must be easy to clean. In addition, the automotive designer must provide satisfactory performance so that the interior will not fade or change color.

It must have resistance to wear and scuffing and enough flexibility, and yet not too much, so that there is no abnormal stretch or shrinkage causing improper fitting. Thus plastics have almost completely replaced the old materials, with sheet-formed parts growing in popularity.

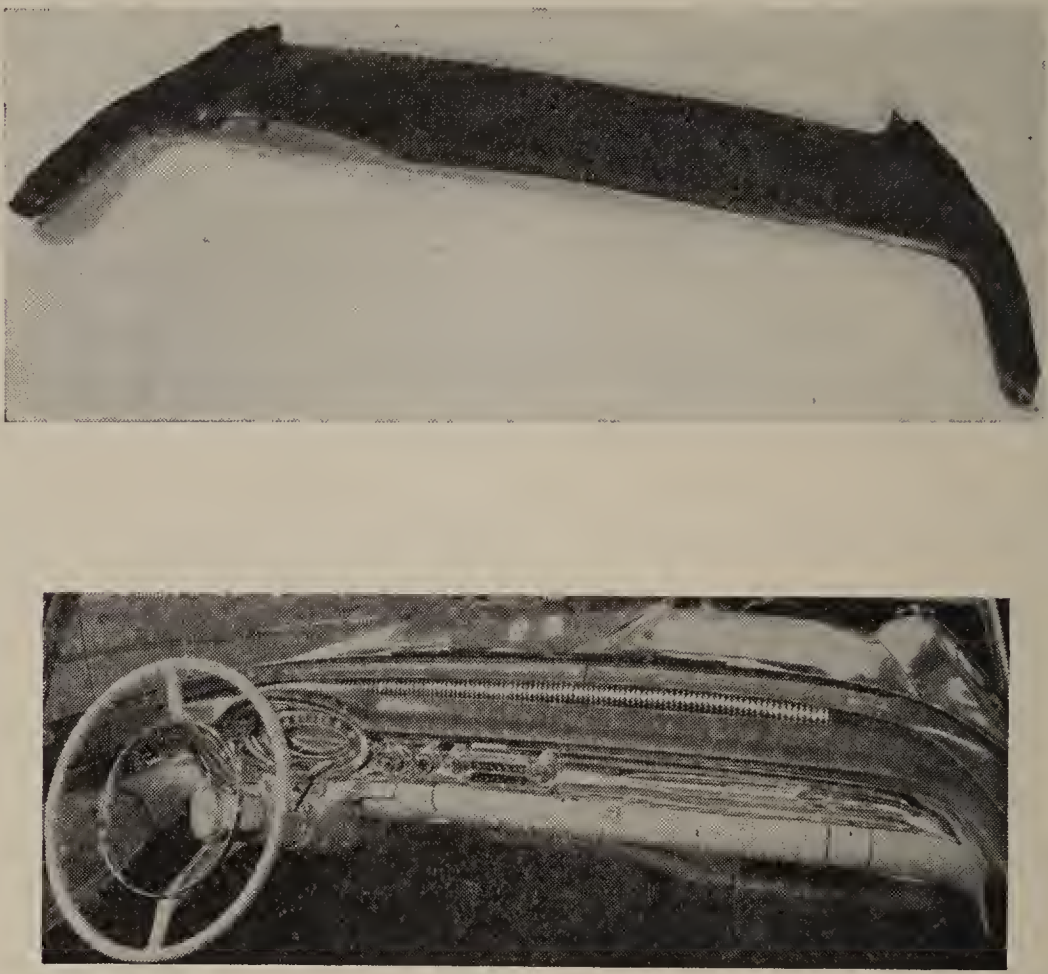

Figure 2–2. Automotive safety dashboard. A vacuum-formed safety dashboard trimmed and filled with polyurethane foam, used in many of the new cars. ABS type material retains grain design throughout the sheet forming and foaming operations. Good dimensional forming provides easy assembly to the car frame. Colors are selected to blend with the decor of the modern car styling.

The padded instrument pad, or "crash pad," and the padded sunshield were converted from metal or hard composition materials for safety reasons. With the large modern high-speed cars many facial injuries or deaths were caused either by collisions or by sudden stops in which the head hit against the instrument panel or sun visor. These new crash pads are manufactured by vacuum forming a shell of approximately .025 inch vinyl sheeting in the shape of the intended pad. This vinyl-formed pad, with the embossed surface on the outside, is placed in a matched jig and usually polyurethane or vinyl is foamed into the shell interior in a calibrated thickness. Thus the extreme lip nearest the driver or front seat passenger is thick and decreases toward the front of the car. These complete pads installed over instrument panels are credited not only with preventing many permanent disfigurements but also with saving many lives. Formerly found only in certain models, this feature is now being incorporated in most all cars and some trucks are even using this type pad.

The headliner or the inside ceiling was first tried on station wagon tops and proved very economical. Made of a styrene blend or a rigid plastic, approximately .035 inch thick, it experienced one difficulty when it developed a resonance or drumming sound from vibration. Present trends in passenger cars indicate a design of several pieces with perforations to achieve the proper acoustics.

At present the side panels or door panels are built up of .006 to .020 inch flexible vinyls embossed with the design, some cotton padding for shock absorption, and a back of hard board approximately .100 inch thick. This forms a beautiful permanent interior lining. However, the present trend is for automobiles to achieve the built-in look now given to refrigerator doors. The door interior will be recessed toward the outside of the car with the arm rest part of the design. This one-piece design, a natural for sheet forming, will give considerably more seat or elbow room. Rigid parts such as seat kick pads and strut covers are fabricated from a ⅛-inch thick styrene blend, a tough wear-resistant plastic with a color embossed surface which will resist kicking, scuffing, and hard wear.

These parts combine beauty with utility. This same material is used for compartment liners and interior covers but generally the embossed surface is omitted.

Metalized "Mylar" is a highly lustrous plastic used as a decorative trim. It is extremely thin (only approximately .001 inch thick) and strong so it is generally combined or laminated to another material for rigidity. It is embossed or formed only to a slight depth, but it has unusual brilliance and color. In general, the sheet-forming picture in the automotive industry is extremely bright since plastics have largely taken over the interiors of cars. For structural parts there is little being done, but future materials may provide an answer to this problem.

## Lighting

Since modern architecture is no longer dependent on external windows for illumination, interior lighting has become a major part of architectural design. Many architects designing modern buildings which require fluorescent lighting or illuminated ceilings use sheet forming to produce the beautiful glareless light required. The fluorescent lighting using sheet-formed plastics is at present manufactured in two different designs.

In the first design, the stress is on rigidity. It is necessary therefore to use a heavy translucent acrylic plastic or "Plexiglas," approximately .100 inch thick. These lighting diffusers are beautiful and highly uniform but they are also expensive.

A less expensive design is that in which the basic material is a .020 inch translucent oriented styrene formed into a low-profile panel. This panel being light in weight is quite a bit less expensive but some added cost is entailed in adapting the fixture to hold the diffuser.

Completely illuminated ceilings or sections of ceilings are actually dummy ceilings made of plastics placed 12 to 18 inches below the real ceiling. This modern approach to lighting

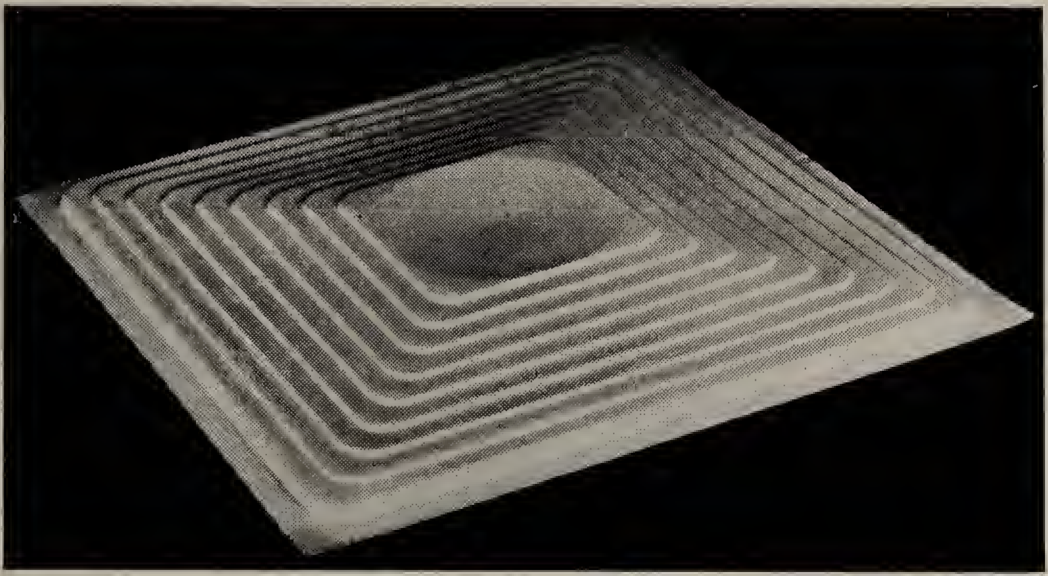

Figure 2–3. Illuminated ceiling panel made of .020 inch oriented styrene measuring 24 × 24 in. A special formulation for lighting provides a soft even illumination. The panel rests on the 1 in. lips and may be snapped out of place for changing bulbs or for cleaning. In case of fire, the heat will shrink the plastic, and it will drop out of the holder, allowing the sprinklers to operate properly.

can be achieved with two different materials, depending on local requirements.

For a fully fireproof ceiling a .020 inch rigid translucent vinyl material is used. The panels are made so that they can be removed for both cleaning and changing bulbs. Some difficulty has been experienced with insects and dirt dropping on top of the panels giving an ugly appearance to the ceiling when illuminated. An improved version of this design utilizes a thin film of vinyl plastic attached to the upper part of the reflector, forming a space between the film and the diffuser. When light hits the upper film it is diffused so that the lower diffuser does not pick up any foreign objects. Since the sprinkler system is above the panel it is important that the panels be fitted loosely so that the weight of the water hitting against them will dislodge them from the opening.

These ceilings are also made of panels manufactured from .020 inch oriented styrene. When subjected to heating oriented styrene immediately shrinks and the panels thus fall out of the holders clearing the sprinklers for activity. The present diffuser panel sizes are:

1′ × 4′
2′ × 2′
2′ × 4′
3′ × 3′
4′ × 4′

Some architects are presently designing around a 5 × 5 foot panel.

The illuminated type shades or globes are manufactured with considerable beauty and utility. One company manufactures many decorative type globes by forming an upper and lower half, similar to a lantern, and then snapping the two together with a preformed undercut. Such globes are made of a vinyl material of approximately .020 inch and have been produced in sizes up to 3 feet in diameter.

Another manufacturer makes regular cylindrical lampshades by embossing them in the flat and then rolling them around, similar to a parchment shade. In order to achieve various designs he uses a standard box into which wire, reed slats, and metal are arranged in a pattern over a wire cloth. The entire plate is then sprayed with a lacquer to hold it in place. Many unusual designs can be made quickly and inexpensively, thus the manufacturer can make custom or original designs to meet his demand.

Many beautiful designs may be produced using sheet-formed illuminated wall panels, placques, or shower doors. Many of these items may not be mass produced but may be designed and used only in one installation. The results are startling and these is no limit to the effects that can be obtained.

## Signs and Displays

As pointed out earlier, the use of sheet formed parts in the sign and display field is enormous. Many sign and display products are short run projects. Attempts in the past to use injection molding were generally ruled out because of the high tool cost. When sheet forming became available it was a natural for this industry due to its low tool cost, low capital investment, variety of materials to work from, and the low unit cost. Not only are short runs economical but the saleability of beautiful three-dimensional displays far exceeds all other materials.

One of the largest segments of this field is the use of displays which have been pre-printed or pre-decorated. The technique for pre-printed displays is to have the flat sheet printed, silk-screened or otherwise decorated. The planned distortion of this pattern when heated and formed in a three-dimensional mold will result in a beautiful product with the colors in the correct position. Many items of this type can be manufactured, prominent of which are wall placques, medallions, stick-on displays, and magnified products.

There is a wide selection of sheet materials to choose from but in general cellulose acetate, cellulose acetate butyrate, vinyl, and styrene are most commonly used. Thicknesses vary from .005 to .030 inch; however products up to ⅛ inch thick have been manufactured economically. The single sheet-formed part usually comprises the entire product, but it may be combined with cardboard, wood, or metal to form an attractive display.

For an illuminated display the same materials as used above will be satisfactory, but they must be translucent for proper lighting results. The same technique of pre-printing and forming is used, but greater care must be taken with translucent paints and colors to give the desired effects under illumination.

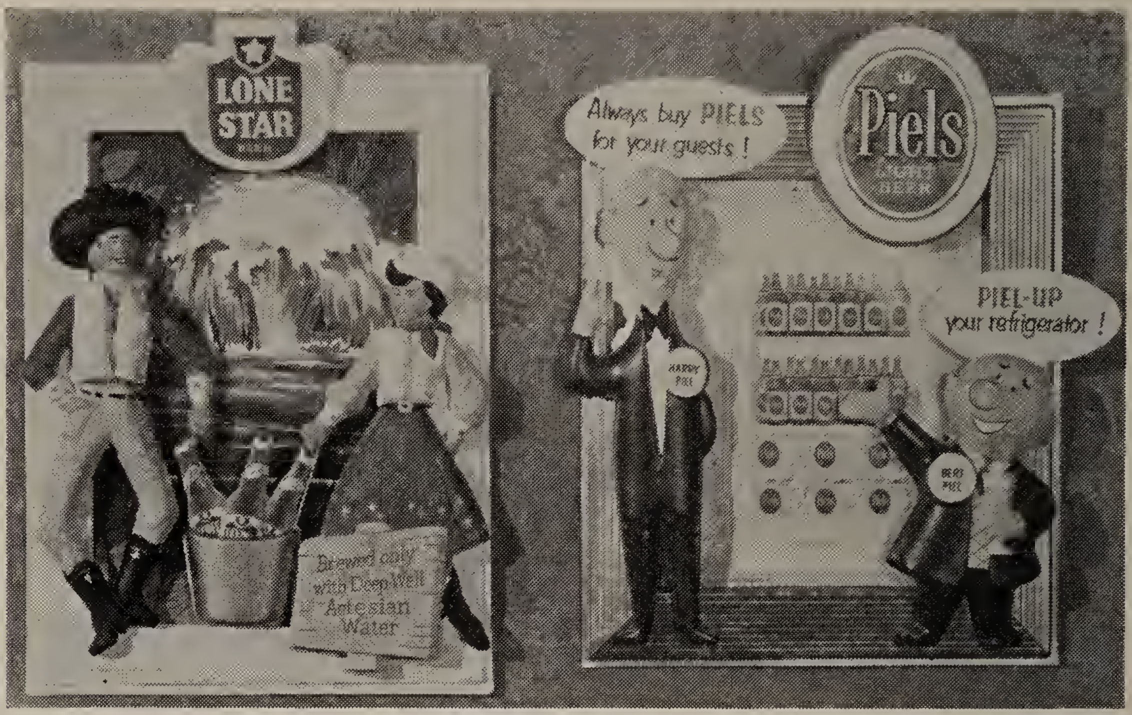
LONE STAR
Brewed only with Deep Well Artesian Water
Always buy PIELS for your guests !
Piels
PIEL-UP your refrigerator !

Figure 2–4. Pre-printed displays made by vacuum forming and the drape process. These are the best examples of the art of pre-decorated advertising displays. Made of .020 in. calendered vinyl, each display measures approximately 16 × 18 in. and is comprised of four plastic parts adhered together. The decorative parts are lithographed in seven colors and the solid colors silk-screened. Note the excellent registration of the colors which continued throughout the production run. (*Courtesy Majestic Creations*)

The sheet formed three-dimensional part is mounted on a back of cardboard, wood, or metal which holds the lighting units. The plastic front is usually stapled to the back but it may be glued or otherwise mechanically locked. The lighting units must be carefully placed so that the resultant display will be properly illuminated. They must also be placed so the heat from the lamps will not distort the product.

The materials for outdoor use are generally more expensive because of the more rigid requirements. Acrylic or "Plexiglas," cellulose acetate butyrate, styrene blend, and vinyl are generally acceptable. These materials have low moisture absorption, are stable against high humidity, resistant to ultraviolet rays, and possess high-impact resistance against the elements.

Many signs in gasoline stations, outdoor mercantile signs, traffic signs and the like, both illuminated and unilluminated, are sheet formed. Acrylic signs up to ½ inch thick have been sheet formed; however, much of the work is in the range of .060 to .250 inch. Many of these signs are constructed of transparent material rather than translucent material and are formed with the decorated side inward. This method not only protects the decoration and color from damage and from the elements but also produces a high glossy surface which adds to the beauty of the display.

Formed plastic letters are sheet formed and may be obtained in various sizes, from tiny ones which you can hold in your hand to those which require two men to lift. These are usually made of a colored material and are generally cemented to the basic sign which may be of plastic or some other material.

Many transparent thermoplastic sheets can now be metalized. This is done by vacuum depositing a very thin film of silver or like metals. Any color may be obtained and a high reflective surface results. The most common materials are cellulose acetate and cellulose acetate butyrate, usually from .005 to .030 inch thick. Sheet-formed items such as three-dimensional displays, picture frames, formed plaques, medallions, and magnified metal products have been manufactured. While the original material is more expensive than plain plastic sheet it is usually used without any other decoration, thus a complete product may be made at one stroke of the sheet-forming press.

## Counter Displays

While many of the signs and displays are produced from transparent and decorated sheets, counter displays and the like are usually not similarly decorated. The items commonly sheet formed are as follows:

girdle displays
jewelry trays
brassiere forms
counter displays with change racks

These employ heavier plastics such as styrene copolymer and styrene blend sheets although cellulose acetate, cellulose acetate butyrate, and some others may be used. Since these

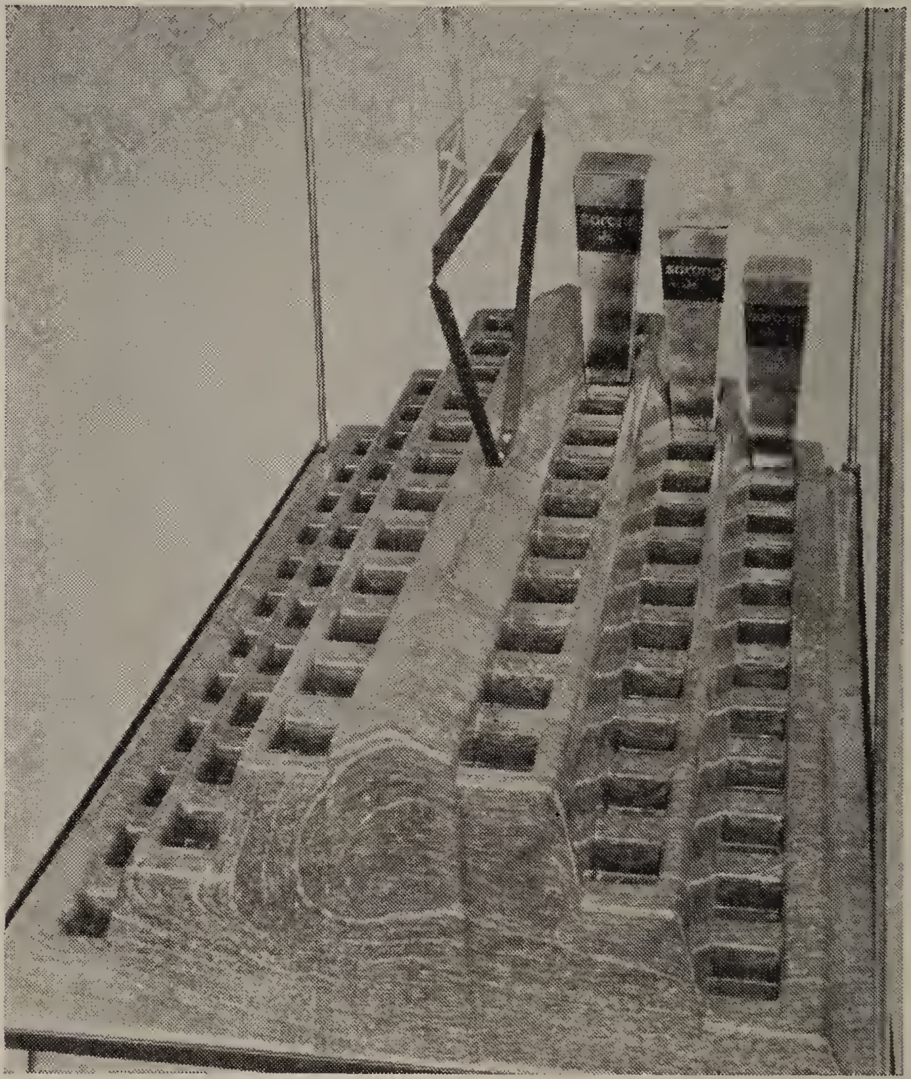

Figure 2–5. The above counter display demonstrates the size to which sheet forming plastics can be stretched. This display measures 24 × 36 in. and is 12 in. high. Formed of $\frac{5}{32}$ in. styrene copolymer, the preprinted decorative finish has stretched uniformly with the plastic. Using a combination type of forming, this has a drape male section while the individual square recesses are formed by straight vacuum. (*Courtesy Newhart Products*)

items require rigidity and strength to hold the displayed products the sheet thicknesses range from .020 to .125 inch.

Some companies produce a plastic sheet printed with a wood grain or pattern which, when three-dimensionally formed, results in attractive displays resembling finely finished wood. Many variations of sheet surfacing are possible such as grain or leatherette finishes but many displays use the plain sheet with good effect. Flocked sheets are also available and when formed they result in a soft velvety display for silverware, jewelry or similar luxury products.

## Christmas Decorations

No discussion of sheet-formed products is complete without mentioning Christmas decorations. This was one of the first fields in which sheet forming was successful.

The Christmas decoration field, like the display field, is a variety field subject to short product life. Some products may be used only one season, when the consumer demands new, novel products for the next season. Consequently, although plastics were used extensively for socket and lighting components, they were rarely used for decorative purposes.

Injection molding was tried but, again, the high tooling cost prevented amortization, except over a long period of time. Because these injection molded parts required much greater thicknesses than sheet forming, product prices were extremely high and, consequently, requirements were low.

The use of pre-decoration is a “must” for Christmas items. These range in size from a few square inches to Santas and similar decorations standing 6 feet high. Both illuminated and unilluminated items are made although in general the illuminated products are more extensively produced.

Because of the fireproof nature of vinyl it has been used almost universally. For indoor items the thickness varies from

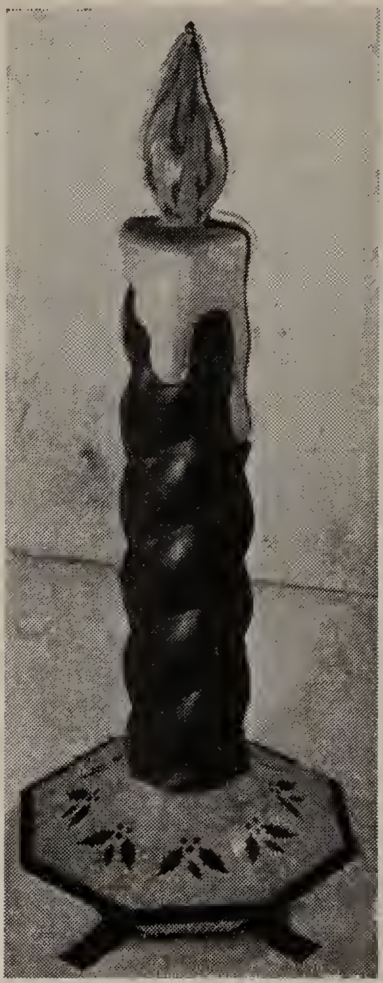

Figure 2–6. A Christmas display. Several sheet-formed parts are used to form an attractive display made of .020 in. calendered vinyl. These parts are pre-decorated by silk screening. The bottom two parts are joined together at the edges by staples, and the candle parts are stapled at the edges. Measuring over 3 ft tall, this product has a metal frame to which the wiring harness is attached to provide a series of lights within the candle. This beautiful display is used both indoors and outdoors. (*Courtesy Noma Lights*)

.010 to approximately .020 inch. For outdoor items thicknesses range up to .040 and sometimes .060 inch. The lighting of these products is similar to that described for display items.

While most of the decorations are one-sided and may be viewed from only one direction, many of the items, such as candles, are made from three or four sheet-formed parts assembled together. Most of the outdoor decorations for homes are sheet-formed. Many of the municipal decorations found in business districts during the Yuletide season are also sheet-formed. Despite their seasonal nature much care is taken to protect the unit against the elements. Without sheet forming we would not have the many beautiful Christmas displays which brightened the Yuletide season.

## Industrial Applications

Many industrial components can be sheet formed using the heavier, high-impact type materials, i.e.,

Tote boxes
Assembly jigs
Machine enclosures
Machine guards
Photographic trays
Electric switch backs

Styrene copolymer and styrene blend materials up to 3/16 inch thick are generally used for industrial components. Many of the materials have a grained exterior so that they combine attractiveness as well as utility. Products made of the styrene

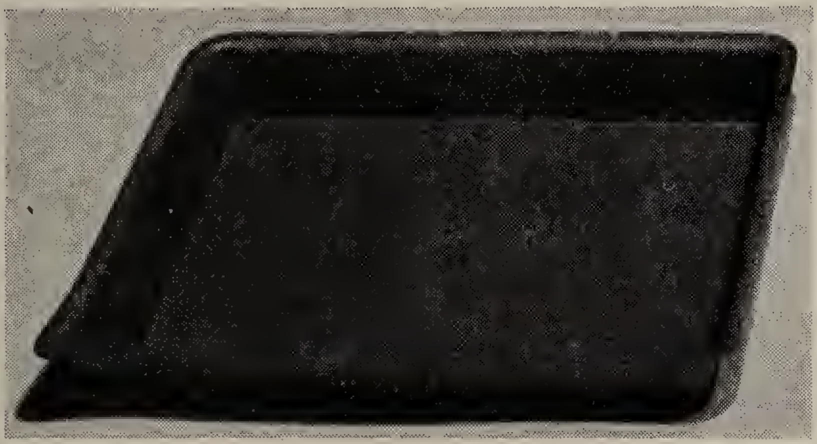

Figure 2–7. This photographic tray, made of heavy-guage polyvinyl chloride, has excellent resistance to the chemicals used in photography. Sheet formed by the drape process, these parts are produced economically. This material has great rigidity enabling it to be handled safely when filled.

blend sheets have a tremendously high impact and can take considerable abuse. These materials require a special skill to form them correctly as well as the most precise equipment. Although this particular field is expanding, competition from steel and the like must be carefully considered in most applications.

Photographic trays which require high acid resistance use a material called polyvinyl chloride which combines high strength with high chemical resistance. Advancements in this field are expected to be considerable when this material can be more easily obtained and the techniques of forming can be further developed.

## Toys

Sheet forming in the toy field is an up and coming manufacturing process. Although this method offers many advantages to the toy manufacturer it must, of necessity, compete with many of the presently known methods such as injection molding and the various metal fabricating processes. It is neither feasible nor economical to compete with injection molded parts but rather to produce certain toys that cannot be manufactured by injection molding. Because of this competition it is necessary to know certain rules in determining items to be made by sheet forming.

1. It is economical when the area is large and of thin wall section because the thickness of sheet-formed parts is usually considerably less than that of any other process.
2. The tool cost of sheet forming is considerably less than that of any other plastic process; therefore where the total life of a toy is short, and most of them are, it is sometimes more economical to use sheet forming.
3. Where quick production is required sheet forming has a

considerable advantage since the entire process can sometimes be set up in days, whereas injection moldings require months.

4. Beautifully textured surfaces or soft materials which are difficult, and sometimes impossible, by injection molding can be sheet-formed.

5. Where low volume controls the item, sheet-formed toys may be manufactured more economically.

6. Where considerable decoration is required a sheet formed part with its pre-decoration has many more advantages than an injection molded part which has to be sprayed or decorated on curved surfaces.

While it is important to know the above rules, many other factors such as the choice of materials enter into the picture as will be shown later. Some of the toys presently made by sheet forming are as follows:

Party hats
Hobby horses
Doll faces
Blackboards
Games and play sets
Halloween masks
Paint sets
Inflatable toys
Toy automobiles
Toy boats
Airplane kits

To design an economical item properly one must take advantage of the thin guage plastics. Most of the thermoplastic materials, including the thin guages, have excellent impact strength. Where greater rigidity is required it is a simple matter to form ribs and reinforcing patterns. The toy designer learns to work with these tricks and can produce a rigid part out of a very thin plastic.

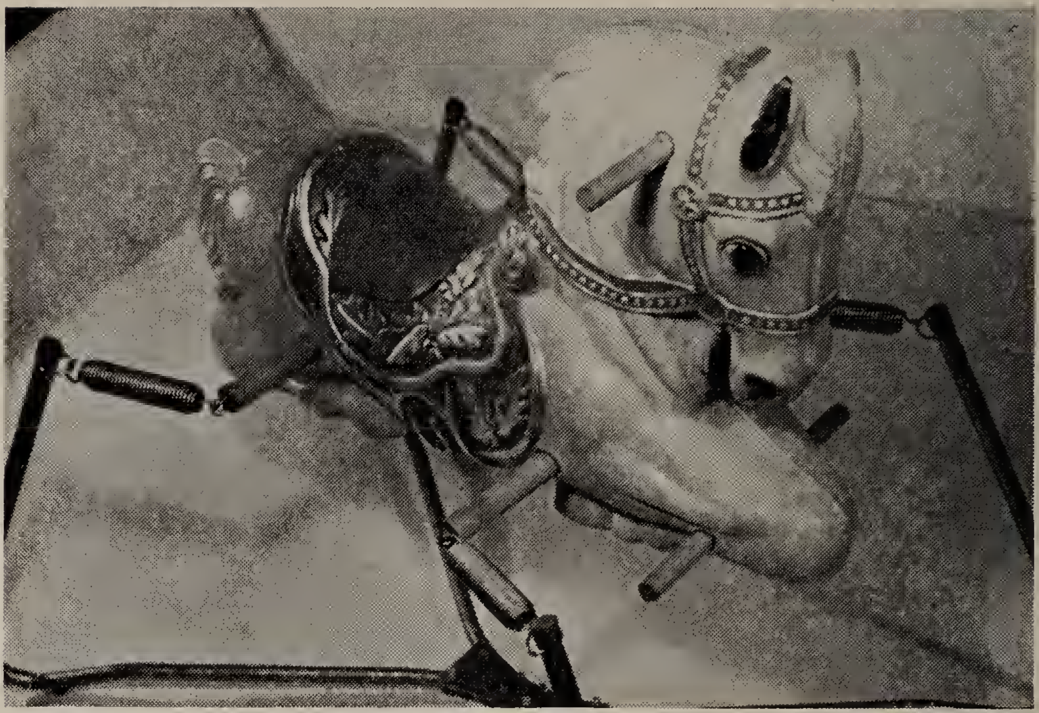

Figure 2–8. This hobby horse is an excellent example of a 2-piece sheet-formed product, the two halves of which are made on a single mold. The material is $\frac{3}{16}$ in. styrene copolymer and the matching joint is formed with an interlocking lap. The two halves are cemented together and decorated by spraying. The product has high impact and excellent durability. (*Courtesy King Plastics*)

Sometimes toys are manufactured by sheet forming to replace the same item manufactured of another material. A good example of this is the halloween face mask. Formerly these were made of slush cast rubber which required many molds to obtain proper production. After casting, the masks had to be cleaned of all flush, and then they had to be decorated by hand. In designing a mask for sheet forming, a flexible sheet of .020 inch vinyl is pre-painted with four basic colors in a continuous run of approximately 10,000 yards. Sections containing one dozen masks each are then cut off from the main roll and sheet formed. The masks are then trimmed at the same time making a set of twelve different faces. Where the rubber masks sold for 49¢, these were able to be sold for 29¢. They not only replaced the rubber masks but also competed with the cheesecloth masks which were generally considered unsatisfactory due to flammability and poor detail. Though the individual masks were less expensive than the former ones, sales were increased many times over.

Doll faces are made of similar materials. However, since a more exact replica of expression is required, decorating is done after forming. The number of doll faces made is enormous, running into many millions, and since orders are received for small runs all the molds are constructed of the same size and use the same size sheet. The great interchangability of sheet-forming molds is thus demonstrated; the total time to change from one mold to another only takes three minutes.

The pre-printed game is another item which runs into the millions annually. Various items such as golf games, toy railroads, battlefields, TV games, etc., appear on the market every year. Most of the materials available for sheet forming are used for these depending on the effect that is desired or the strength of the final part. Toy hobby horses and automobile housings up to 6 feet long require great strength and the ability to take the abuse of a romping child. The speed of sheet forming is essential to the toy manufacturer. He can go from pilot model to full production in a matter of days, thus meeting the seasonal requirements.

## Aircraft

Prior to World War II the development of acrylics made possible many of the formed parts for our bombers and fighters such as canopies, windows, radar housings, and nose housings. Generally, up to about ⅜ inch thick, these parts have stringent requirements not only for strength and uniform thickness but also for optical properties to prevent distortion. In order to manufacture within these requirements such materials are formed by a very difficult and exact process. Where possible free blowing is employed in which a ring clamp is used and air is introduced to blow up a shape in the heated plastic. Most forms are more difficult and require special techniques which will be described later.

Many of the aircraft companies are fabricating vinyl and styrene blend panels for interior trim, doors, seat panels, and window frames since the low cost, low production requirements of the aircraft industry fit in with the low tooling required of sheet forming.

### Military

Much credit must be given to the government for the primary development of sheet forming. The appearance of preprinted and formed military maps in the middle 1940's was a great technological development. From aerial surveys and known data a very exact master is prepared of plaster. This is duplicated and made into molds, also of plaster. A .015 inch vinyl sheet is printed by the same process used for a flat map but with the planned distortion, including topographical lines, to show elevation. When sheet-formed, the map has the terrain accurately duplicated with towns, rivers, and elevation, including the colors, in accordance with military standards. These maps are of infinite value to the military government of the United States.

As for other military applications, there are only a very few at the present. However, various branches of the Quartermaster Corps are undertaking sheet-forming experiments to test military packaging for future production.

### Household

In the last few years the development of household items has been on the upswing. Some of the present items are:

Drainboards
Medicine cabinets
Bath mats
Place mats
Bureau drawers
Drawer dust liners
Picture frames
Card table tops
Window valances
Shower floors
Shower doors
Picnic basket liners
Tile sections
Artificial brick and similar wall covering
Flower pots, etc.

Items such as place mats and bath mats have been produced by the millions for the last few years. Formed on metal sprayed molds, which exactly duplicate any known pattern, six or eight can usually be produced at a single time. These have been readily accepted by housewives because of their cleanliness.

A simple item such as a dust liner for a drawer, which is formed with approximately a ½ inch lip, has replaced newspaper or wrapping paper in many millions of drawers. It is far more satisfactory and can be easily cleaned.

Coming to the fore is the use of formed plastics for such items as bureau drawers and desk drawers. Wood is becoming scarcer, and with woodworking labor costs rising these plastic items are now becoming economic.

A wall covering utilizing artificial brick as a design has appeared in many modern homes and public buildings. Many designers are working on floor-to-ceiling coverings of formed plastic with embossed designs which, when feasible, would

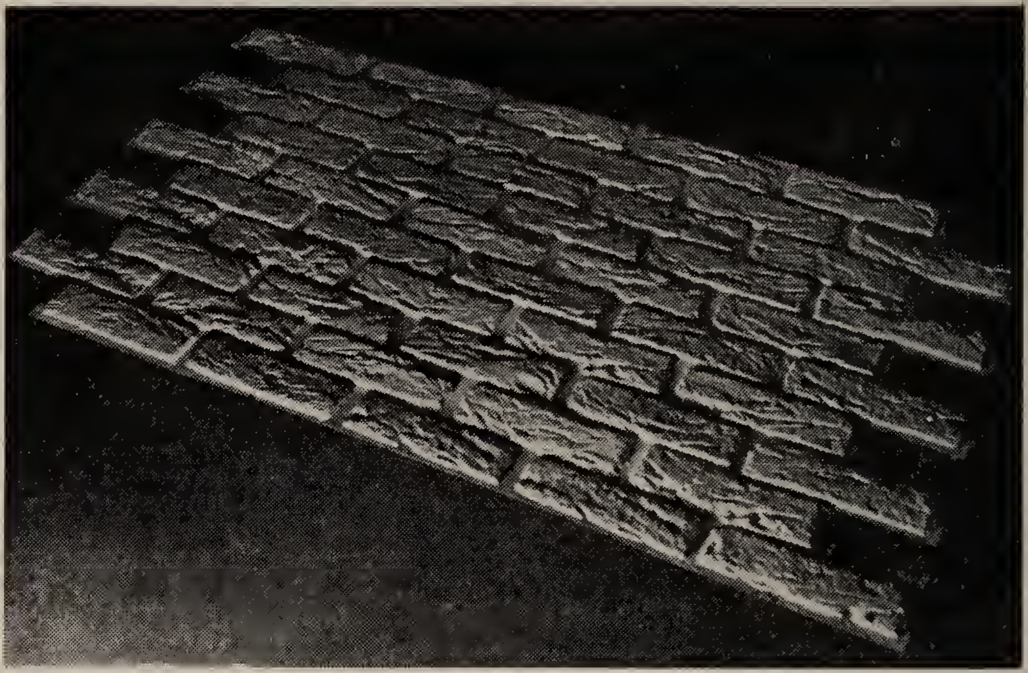

Figure 2–9. A decorative brick panel made of .015 in. vinyl. Panels with many decorative brick or stone patterns are being used in many homes and business establishments. They are attached by a special cement provided by the manufacturer and the interlocking design allows for continuous wall patterns without unsightly joints. Such panels are completely fireproof. (*Courtesy National Vacuum Corp.*)

eliminate painting or interior decorating since they may be easily washed and have permanent coloring. It is expected that this will become one of the largest phases of the sheet-forming industry.

## Premium and Novelties

In the field of premium and novelties it is almost impossible to list the many hundreds of items which have been manufactured. Some of the better ones are as follows:

Pre-printed wallets
Ring binders or book covers
Ice cream dishes
Give-away premiums such as medallions, small toys and the like run into many millions

Decorative placques
Molds for toy kits
Sand forms, etc.

Of the above the largest item is the ice cream dish which has replaced paper in many of the roadside stands. Made in three sizes—one for a dish of ice cream, one for a sundae, and one for a banana split—these are shaped from .020 inch styrene copolymer sheets in many colors. Since these are either given to the customer or thrown away, no dishwashing facilities are required in these places with the added saving of labor.

Wallets which have beautiful designs in many colors and an embossed pattern are mass produced on simple sheet-forming machines. Made of .020 inch flexible vinyl, in groups of ten to twenty at a time, these are cut apart, and heat-sealed to plain plastic to form the wallets. Because of the beauty and low cost of these wallets many of the older materials used for this purpose have been replaced.

There is no limit to the number of novelty items that can be made by the sheet-forming process. The low cost of both the molds and the material enables many new items not previously possible to be manufactured.

## Specialty Items

While many items do not fall in the above categories a few of them are meeting with spectacular success. One item which is now being manufactured is TV scenery, such as enormous panels, pillars, rocks, etc., which is fabricated on simple wood molds. Few of us realize the painstaking care necessary to produce such sets. Sheet forming has not only been able to produce these at a lower cost but also to make items which give real meaning or feeling to the sets.

## Packaging

One of the most lucrative fields for the sheet former is in the production of plastic packages. These range in size from tiny plastic packages (1″ × 1½″) of .003 inch film to strong rigid containers for tools. Although original designs a few years ago required only moderate production runs the rapid public acceptance of this type of package has increased their use to many millions annually. Indeed, some special applications such as small bulbs expect annual production in the tens of millions.

From the number of parts produced annually by sheet forming, packaging is the undisputed leader. Why does the future look so bright for this type of packaging? Sheet forming fills the need long sought by the packaging industry. With the advent of self-service in super markets, 5 & 10 cent stores, and all large volume stores, the product has become the salesman. Visual type packaging is a good salesman. Merchandise is always clean and attractive when it is protected by a strong plastic cover. The buyer can instantly check to see if all the parts have been included such as mounting screws for handles and brackets and keys for locks, and the instructions can be read through the plastic. Loose parts are eliminated since the package can be formed to contain each individual part. The parts are easily wrapped since they are of uniform shape or size and, in the case of carded merchandise, may be hung on hooks by a perforation in the card. Inventory is easy since the salesgirl may check the counter and see what is in each package. Sales are quicker since no time is lost in opening cardboard packages and checking their contents. Fragile parts are held to prevent damage. The stores have no losses due to mishandled parts or incomplete sets where parts have been lost. Pilfering is reduced since the size of the package, especially for carded merchandise, is sufficiently large to prevent easy concealment.

Wherever this type of packaging has been introduced, increased sales have resulted. Yet costs are greater than cardboard boxes, transparent boxes, or loose merchandise. For example, an average carded product in the order of a 3 × 5 inch card may cost from 1½ to 5¢ each, yet the entire retail price has been as low as 15¢ on some items. This is comparable to lessons learned by the cosmetic, toy and perfume industries where attractive packages are often more costly than the product itself, but yet the buying public will purchase these in preference to lower cost, poorly packaged items.

**Carded Merchandise.** Sheet-formed packages take many forms but one of the large-volume users is carded merchandise. The most popular form of carded merchandise is the blister pack in which a sheet-formed blister or bubble, contour-formed to the shape of the product, is assembled to a flat printed card by means of a flange on the edge of the blister.

One way in which this may be assembled is by using staples. Thus the blister or bubble is filled with the merchandise and several staples lock the blister to the card. While this is inexpensive, some buyers object to the unsightly staples and the fact that the flange does not lie flat but tends to curl away from the package. Since it is not economical to use more than three or four staples the package may be weak since the two parts are only held together at several points, and the merchandise may tear the blister from the card in shipping or handling.

An improvement over stapling is the two-card method where the face card with the printing has a cut-out for the blister to fit through, but not the flange. The merchandise is placed in the blister and inserted through the front card. The rear card which is usually folded as part of the face card is folded back and adhered to the back of the face card. This locks the blister in place and holds it securely around the flanges. The two cards may be held together by stapling them around the edges or by a self-adhesive cement which locks instantly upon contact.

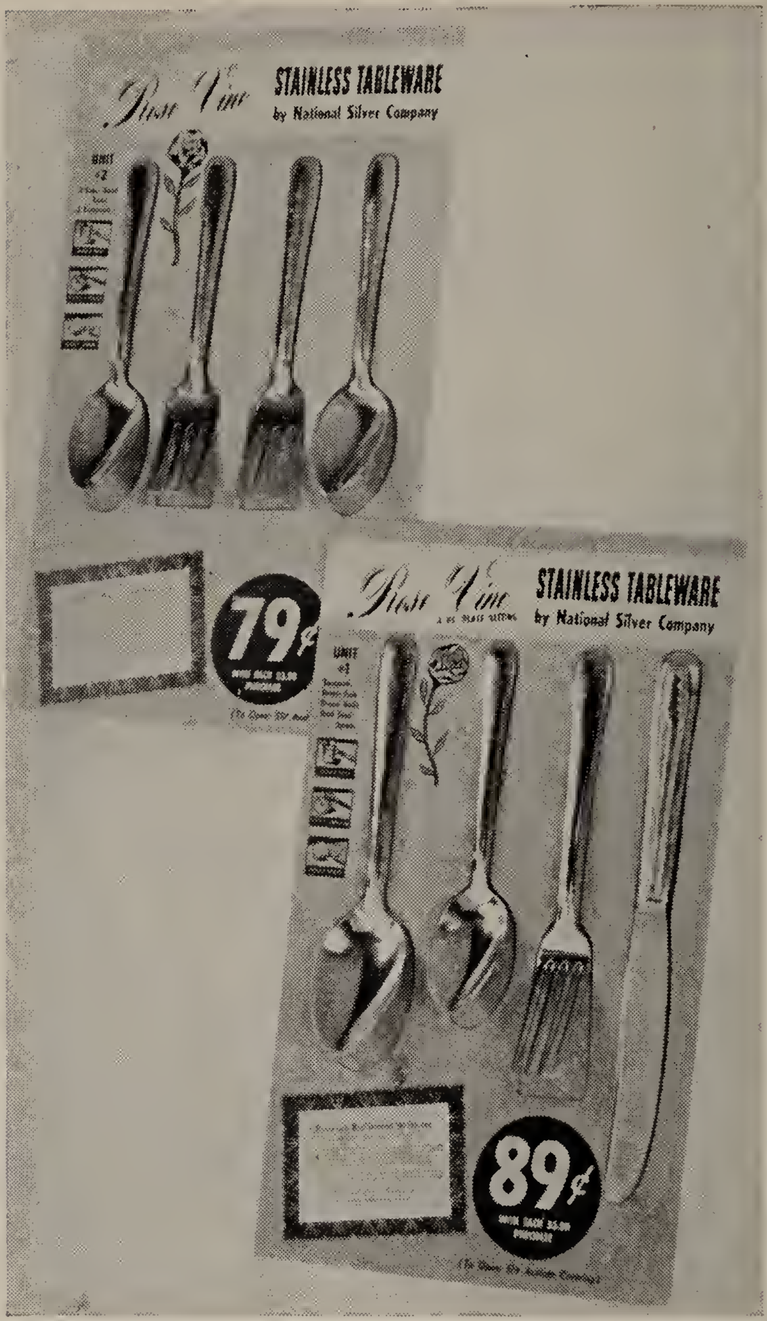

Figure 2–10. Blister pack. Typical blister application protects the product from handling, yet visually demonstrates its beauty. Formed from .015 in. cellulose acetate the blister with the product in place is pressed through the card face. A backing cardboard locked to the face card by adhesive holds the package together. (*Courtesy Emet Plastics*)

Another type of carded merchandise uses a single card which has been coated with a thermoplastic adhesive. This does not cost as much as the other methods. This adhesive is dry at room temperature and the card may even be printed after the adhesive is applied. The plastic blister with the merchandise inside is then heat-sealed by the flanges to the card. Machines are available which will do from twenty to fifty cards at one time.

Another variation is to make a blister with a wide flange on two sides. This flange is then bent by heat to form a back flap. The card is slid under the flange between these flaps with the merchandise in place. This is known as a slide pack since the card may be slid out of the package in the stores to remove and inspect the merchandise. Most suppliers put one staple in the combined card and plastic to prevent shifting of the merchandise during shipping.

Bubbles or blisters for the above applications are usually made of cellulose acetate or cellulose acetate butyrate from .003 to .020 inch thick because of their low cost. Some blisters have been made of calendered vinyl, oriented styrene, and ethyl cellulose but these are not as extensively used.

**Carded Skin Pack.** The skin pack and variations of skin packaging are popular forms of merchandising. Skin packing is a process in which a thermoplastic film is sheet formed directly over a product which is lying on a card coated with a thermoplastic adhesive. The action of the heat and pressure pulls the plastic around the product enveloping it completely and activating the adhesive, thus laminating the plastic to the board. This forms a tight, tough film over the product. No molds are required. The card however is more expensive than the others since it must be specially prepared by scoring or perforating for the vacuum or pressure required, must be coated with a thermoplastic adhesive, and must be slightly heavier to resist the pull of the plastic. Usually much thinner films are used since the plastic is completely supported by the product. Cellulose acetate, cellulose acetate butyrate, and cast vinyl film ranging in thickness from .002 to .0075 inch are generally used for this application. Vinyl film gives a better product since there is no residual strain and card curling is eliminated, especially with the larger cards. Skin packing has been successfully used on items as large as 16 × 22 inches.

Generally, skin packed products are of the lower profile type and of regular proportions. Since the plastic conforms to the shape of the article it may become exceedingly thin or burst in deep undercuts. Skin packed products appear to have a high luster since the product is immediately adjacent to the plastic film; they also have good impact and abrasion resistance. Soft articles such as gloves, handkerchiefs, and socks may be successfully skin packed by using controlled pressures to reduce crushing. In one variation of skin packing, called "imbedment," the product is imbedded in a sheet of plastic but it is not locked to the board at the time of sheet forming. The above plastics are also used for this process and the imbedded article with a flange is treated exactly as a bubble or blister pack and may be stapled, heat sealed, or mechanically locked to the card. The difficulties with high profile items may be eliminated by forming the article on a contoured step and reducing the undercut or breaking which may occur in normal skin packing.

**Carded Snap Pack.** An inexpensive application for such items as ball point pens and uniform products of this type is called "snap pack." In this type of forming the product is imbedded and formed with an undercut around the product. When cut out of the sheet with a flange around the product, it is pushed through the back of the card which has a die cut opening slightly smaller than the product. The product then snaps into place through the front of the card and is completely covered by a thin plastic film. This type of packaging is relatively inexpensive since the film can be extremely thin and only a small amount is required.

**All-Plastic Skin Pack.** A type of packaging which is being used more and more employs either the skin pack or imbedment, with a bottom sheet of thin plastic instead of the card.

The operation is exactly the same as skin packaging except that the bottom is a clear transparent sheet which has been coated with a thermoplastic adhesive. When this package is complete both the front and the back are covered with a clear film, resulting in a beautiful decorative package. This has been used effectively for packaging toys, such as toy soldiers, small airplanes, and packages containing many small parts. Some manufacturers prefer to imbed such parts in a single plastic sheet and then place the entire product in a box, face upward. Thus all the parts are held in place for shipping and yet can be displayed to best advantage.

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**Covers, Lids and Inserts.** Sheet-formed plastics are used extensively in the production of plastic covers, lids, and inserts for paper and cardboard packages. The use of plastics improves the package by providing a window so that the contents may be seen and examined without opening it. A good example of this type of packaging is the lid used to cover paper containers used for potato salads, gelatin salads, fruit, cheeses, and the like. This lid, produced of oriented styrene .010 inch thick, is formed by high pressure since it is a tough hard film. When placed on the container it forms a lustrous window which locks over the lip of the box making it completely leakproof.

Covers are used on cardboard boxes containing entire sets such as cameras with their flash guns and accessories. They not only protect the contents from dust and dirt but they also prevent handling by the customers. Flat covers are used effectively over boxes of playing cards and similar items.

Interior inserts may be contour formed to hold the products thus filling a need long sought for by the cardboard box people. Instead of die-cut cardboard pieces which are usually unattractive, a contoured plastic sheet fits into the interior box holding the various parts in their exact positions so that they may be displayed properly. This plastic part also provides complete protection against damage even to fragile parts. The innumer-

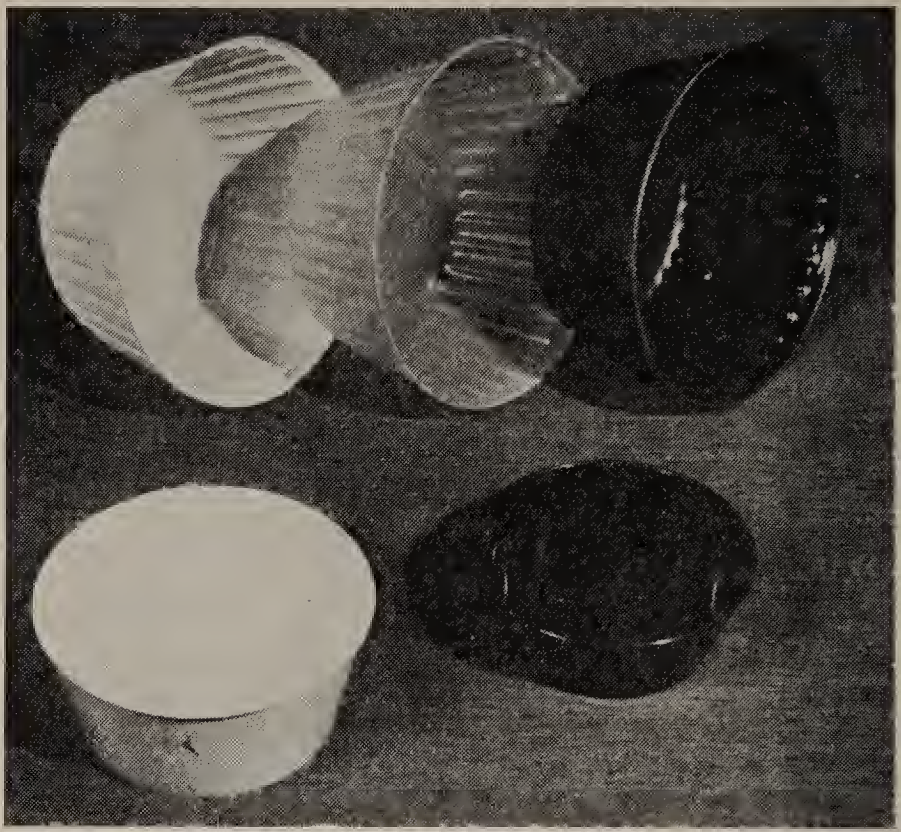


Figure 2–11. Covers and lids produced by sheet forming. Selection of the material and the type of manufacture vary. Use of this type of packaging, despite a higher than cardboard cost, is increasing year by year.

able sheet finishes which are available in plastics make this part very decorative as well. Such items as tool kits containing screw drivers and pliers use inserts of this type. One of the newest developments in this field is the use of a flocked insert in which the plastic sheet is obtained with the flock already on one side. After forming, a beautiful contoured luxurious piece is obtained which is used for silverware, perfumes, etc. These inserts may be obtained in colors to match the decor of the over-all package.

**Complete New 2-Piece Package.** A complete sheet-formed package is used for food as well as for many other consumer items. These packages may be made in two ways:

1. They may be made of two separate pieces—a bottom and a lid.

2. They may be of the folded type where they are folded over a crease between the bottom and the top.

These packages are now used for the following products:

Tools
Electrical parts
Ball bearings
Silverware
Tooth brushes
Candies
Foods such as tomatoes, eggs, cottage cheese, meats.

When used for tools, the bottom is usually of a heavy guage opaque material and the top of a transparent material of a thinner guage. Styrene approximately .060 inch thick will support a good variety of the tools on the market. The cover is usually of .015 inch clear cellulose acetate or cellulose acetate butyrate.

One company uses a bottom formed package to hold electrical supplies and a cover with a formed lip so that it may be slid off the flanges at the bottom to provide easy access.

A good example of the folded type package is that used for hot-house tomatoes. This package is made of .0075 inch cellulose acetate and will hold three or four tomatoes. There was a need for a package in which both sides of the tomato could be inspected at the time of purchase. It is made flat with a half-round hemisphere in the bottom and a half round hemisphere in the top. It is folded along a center crease with the tomatoes in the hemispheres and stapled together at one edge.

When sheet-formed plastics are used for food containers one must be careful to select the proper material for the food being packaged. It is wise to check with your material supplier and to get approval from the various local and national health authorities.

At present there are food packages available for hamburger

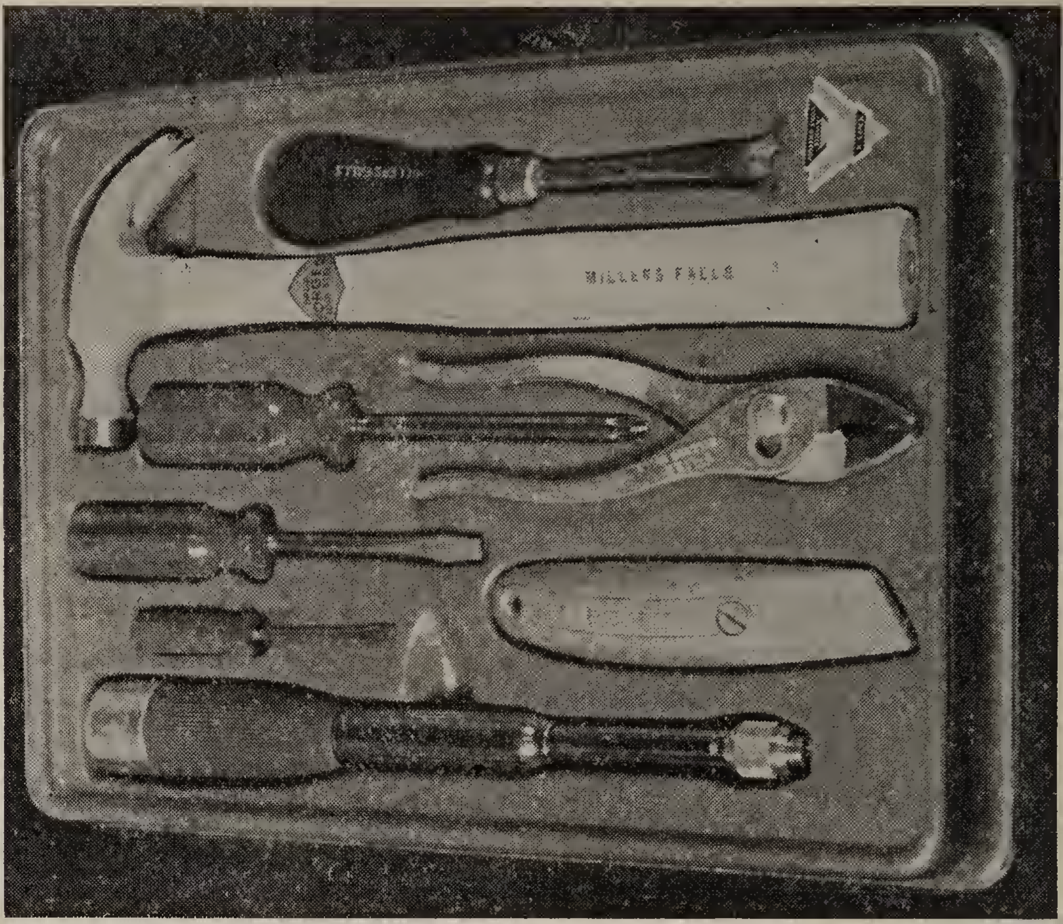


Figure 2–12. A two-piece package of the premium type produced by the sheet forming process. The bottom part of styrene copolymer holds the part securely. The clear acetate cover when placed over the bottom locks the parts in place. The parts may be examined through the transparent cover prior to purchase. There are no losses in this type of package and it resists the abuse of handling in transit. Both the package and merchandise arrive at the retail store ready for displaying. (*Courtesy Jupiter Plastics*)

meat, sliced meats, and cottage cheese. In the package for the hamburger meat the styrene bottom, approximately .020 inch thick, is sheet-formed with a rolled lip. Designed to hold 5 pounds of hamburger, a clear cellophane sheet is pressed down around the product along the interior walls of the package, thus providing a completely protected package. Sliced meats are more difficult to package since the meat tends to discolor when subjected to air. Both oriented styrene and a laminated saran and acetate material have been used effectively. Packages

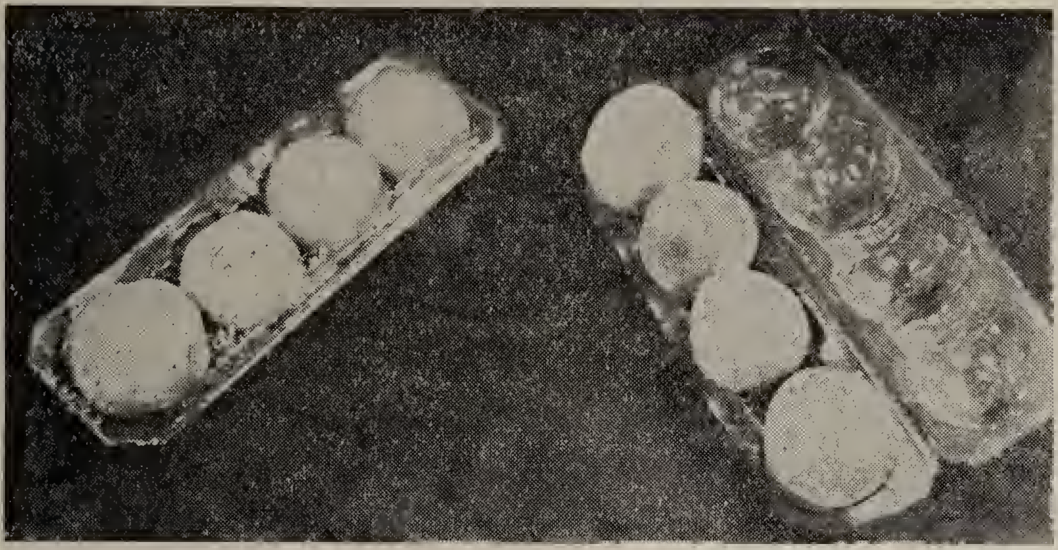


Figure 2–13. This tomato pack, made of .0075 in. cellulose acetate, is completely transparent and the housewife may inspect all sides of the fruit before purchasing it. The two half-spheres are folded over the fruit along a center bend and fastened by 3 staples. The cost of the package is low enough to give active sales to premium tomatoes. (*Courtesy Ultra Plastics*)

for cottage cheese consist of a thick guage polyethylene bottom approximately .020 inch thick and a heat-sealed polyethylene cover .003 inch thick, with a slit opening on one side. The cheese is inserted through the slit, which is then heat-sealed closed.

A new development which shows great promise is one in which a cellulose acetate lid is hermetically sealed to a sheet-formed base containing a steel bearing. The novel part of this package is that the entire interior is filled with oil so that it completely protects the contents from corrosion.

There are many packages of the two-piece design on the market for such items as silverware, hair brushes, and tooth brushes and these are growing in popularity. Such packages are not only made with a transparent top but are frequently made with decorative designs embossed or laminated in the plastic making a very attractive and durable package.

# 3. THE FABRICATION PROCESS

Sheet forming of thermoplastic sheet is in itself the simplest form of manufacturing in the plastics industry. Basically, if a piece of thermoplastic sheet is heated to a temperature between 250 to 450°F it will be so soft that it can easily be formed around or into a one-piece mold mechanically, or by vacuum or air pressure. When held in the mold and allowed to cool, the plastic will retain the exact shape of the mold, duplicating the finest detail.

Molds are relatively inexpensive, and are often not even necessary. When a piece of wood, metal or similar material is placed on the platen of a machine it can be used to make an approximate reproduction in plastic. The simplicity of the process is deceptive however since there may be as many as fifteen different methods. With the many different methods to choose from, considerable experience is required to select the right one. Even the experts disagree not only on the method but even on the name by which it is called.

Commercial equipment is available which will sheet form plastics by as many as five different methods in one machine. However, some processes require the use of homemade equipment since there are no commercial machines available. Thus the method selected must be capable of being used with the equipment available. The accompanying description of sheet forming will have many references to the equipment as well as to the method.

Why does sheet forming require so many processes of fabrication? While many materials may be easily formed by vacuum in their soft, heated form, a vacuum pressure of 14.7 psi is insufficient in some cases to form materials at all or may only result in poor formation. Thus the equipment, method, and molds must be different for these materials, and in some cases air pressures up to 300 psi may be required.

The many products made by sheet forming also influence the type of process selected. In all sheet-forming processes the final product is thinner than the original sheet due to the stretching which takes place. Of course, the ideal product would have uniform thickness throughout. However, all sheet forming processes produce products with thick and thin sections. Some of the processes listed here are used to produce parts of a more uniform section, a deep-drawn part, or an optically clear part such as aircraft canopies, or parts with special features.

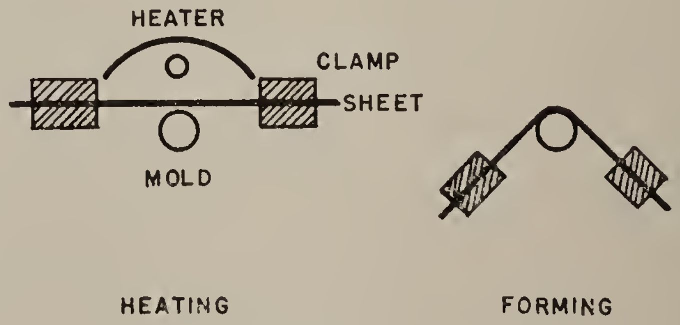
Lest the newcomer be frightened off by the complexities of the processes he must realize that it is doubtful if any one concern uses all of the processes. Most manufacturers use only a few of the processes to sheet-form hundreds of products. Thus a general-purpose machine which can be adapted to several processes is the most popular. There are, of course, specially designed machines available for the production of specific types of products. These will produce a small variety of products more efficiently than the general-purpose machine.

There are also many production techniques which will help the sheet former such as heat shielding to vary the temperature of the plastic sheet for difficult sections; drape assist to preform sections which are close to each other; many others are dictated by the intricacies of the product.

Of all the methods, vacuum forming accounts for a majority of the products now being made by sheet forming. Indeed, until recently the entire process was generally called "vacuum forming" but some of the advances such as pressure forming have required the use of the term "sheet forming" which is understood better. The descriptions given here, accompanied by sectional drawings, indicate the general process used. While the heating is always shown in place, material may be transferred under the heater and to the mold, it may remain under the heater, or it may be heated on both sides. The exact selection, of course, is dictated by the type of machinery used and the product design. Thus, each of the particular processes shown here may be worked in an altered sequence but will produce the part in the same way. It must be understood of course that many of these processes may be combined. In other words, a draping action may be used to form the outer sides of a refrigerator door, a plug to form the butter compartment, and straight vacuum to form the inside—all on one mold and in one sequence of operation. Thus, the ability to understand all the processes is important for the complex products now appearing on the market.

## Mechanical Forming

The oldest method of forming, which has many variations, uses a straight mechanical action without vacuum or air. Essentially, any thermoplastic sheet, if properly heated, may be formed mechanically. Usually heavy mark-off occurs, hence this factor must be given careful consideration. Sheet-metal equipment such as crank presses, benders, air presses, rollers, creasers and curling equipment is used.



Mechanical forming.

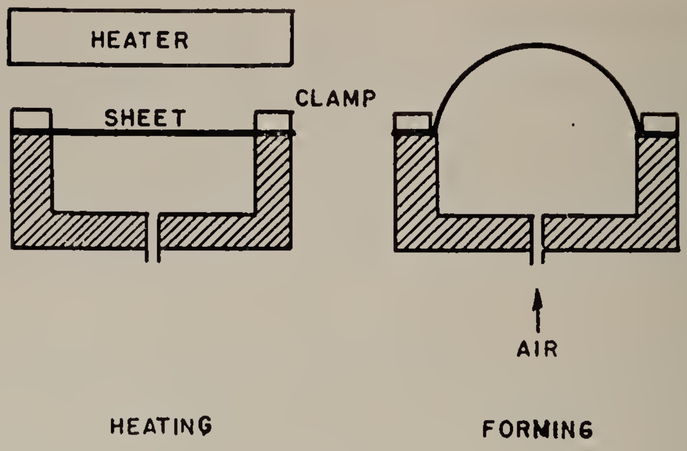
A considerable amount of straight forming and bending is performed in the course of fabricating sheet plastics. For example, in fabricating tubes for packages, the ends of the tube are spun over or beaded against a heated spinning die. The curve of the die rolls the end of the tube over into a perfect bead.

Localized heating is used to bend angles in sheets. The sheet is suspended over a tubular heating element and heated in the area to be bent. The part is then formed in a hinged bender or a sheet-metal brake. In making the line bends care should be taken where the bend exceeds 24 inches in length, since long bends have a tendency to bow. After bending to the required shape, it is necessary to hold the part in the jig until it is cool, since most thermoplastic sheets have plastic memory (the property which tends to revert a heated part to the original flat sheet). When several folds are to be made, heaters can be arranged in various patterns so that all bends may be made simultaneously. A good knowledge of line bending is valuable and can save a considerable amount of money if original designs can be analyzed to determine whether a simple bending operation will suffice.

Considerable mechanical forming is used in the fabrication of automotive seat parts and instrument panels. It is also used in packaging and for locking plastic parts to the mounting boards used in display work.

## Free Blowing and Free Forming

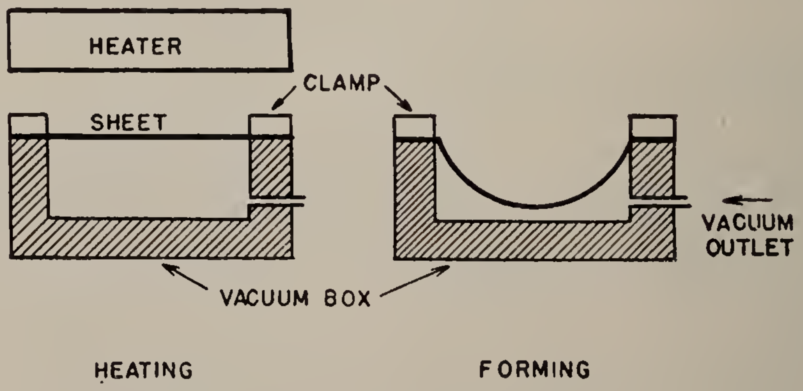
Forming three-dimensional shapes by free blowing or by vacuum free forming requires no molds. The product is shaped entirely by the use of air pressure differentials. Products requiring high optical clarity such as aircraft canopies and sky lights may be formed by free blowing. In this type of forming the plastic sheet is held in a clamp, the inside contour of which



Free blowing.

is the outline of the base of the finished product. The plastic sheet is heated and pressure is then applied, blowing the product to the required shape. Much of the success of this type of forming is due to the individual skill and technique of the operator since he must judge the amount of air necessary.

In free forming, a vacuum box takes the place of the flat blowing plate and the product is drawn inward by vacuum to produce the same type of form. The choice between the use of vacuum and positive pressure depends on the equipment available and on the individual preference of the manufacturer. Vacuum forming is usually preferred because it is safer, easier to control, and simpler to seal. Since the center of the sheet stretches first, this area thins out and therefore cools first, thus a deep drawn part will tend to resemble a fishbowl since the

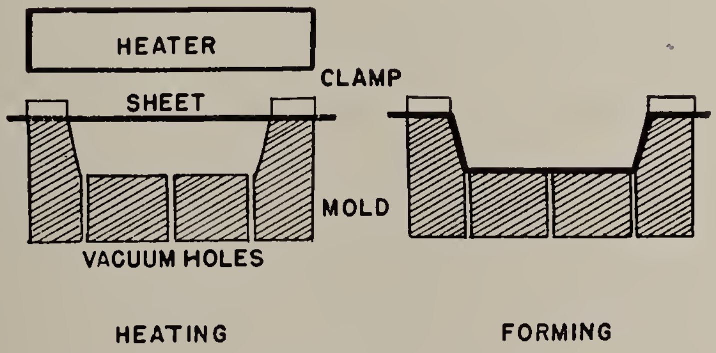


Free forming.

sidewalls expand last. By altering the opening in the clamp a variety of shapes can be formed. There is no possibility of mark-off since the sheet does not touch anything during the process. Cooling is uniform because both sides of the plastic are exposed to the air. A knowledge of this type of forming is valuable in cases where optical clarity or good surface without mark-off is required. A design may be incorporated in the over-all mold to prevent a part from touching the mold surface by shutting off the air flow to or from that section. In general, however, the shapes to which plastic sheet may be free blown or formed are simple and dimensions are hard to achieve, thus it is not too popular in the over-all sheet-forming picture.

## Vacuum Forming in a Female Mold

One of the easiest types of forming at the present time requires the use of vacuum alone to pull the heated sheet into or over the mold. This type of forming may be performed on a machine with straight vacuum or it may be performed on one of the combination forming machines. The plastic sheet is either clamped directly to the mold or held in the clamp directly above the mold. After the plastic sheet is completely heated, vacuum is applied which pulls the plastic into the mold conforming to its every detail. The side closest to the mold will pick up every impression of the mold that the thickness of the



Vacuum forming in a female mold.

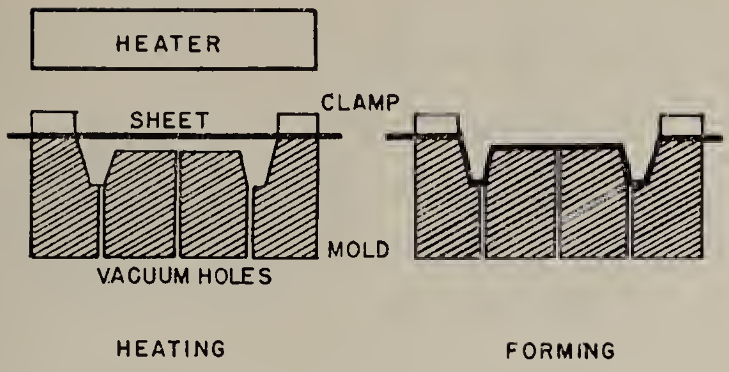
material will allow. The side away from the mold will pick up a less distinct impression since the lines may be rounded over due to the thickness of the sheet. Vacuum holes must be placed in the recesses of the mold so that the part can pull down cleanly. There must also be a sufficient number of vacuum holes so that the area between the sheet and the mold can be evacuated quickly and the plastic sheet does not cool by a slow draw.

Products made by this process are of the low-profile type since the deeper the cavity is the thinner will be the plastic formed. A rule of thumb generally used is that straight vacuum is applied where the diameter of any opening is no less than twice the depth.

For plastic sheets which have been pre-printed by silk-screening or printing, the straight vacuum method gives the best results since the registration in the clamping frame and the even pull of this method result in highly accurate placement of the colors. This type of forming is used extensively in all fields for low-profile work. It is also selected when there is a high profile design or part design, or embossing on the part of the plastic toward the mold such as is used in place mats, bath mats, wallets, automobile door liners, displays, and packaging.

## Straight Vacuum Forming Over a Male Mold

A variation of the straight vacuum method is vacuum forming on a male form placed in a cavity. In this type of forming the thickest section of the plastic part is placed on the top, resulting in a stronger part. However, more waste occurs since the plastic must be drawn down the sides of the female portion sufficiently far to prevent excess thinning at the base of the male plug. Some products with low-profiles are molded economically by this method.



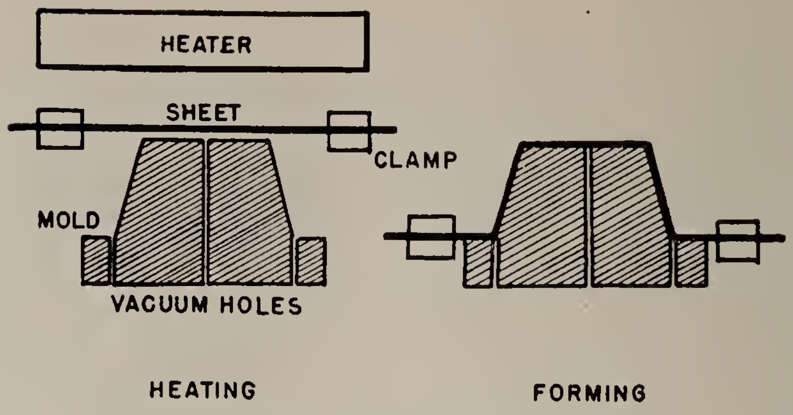
Vacuum forming over a male mold.

In one type of three-dimensional map molded by this process, vacuum is applied to the combination mold before the sheet is heated. As the sheet softens, the vacuum drapes it over the male mold and down around the sides. When the sheet is fully formed, the heat is removed. Proponents of this type of molding claim that greater accuracy of registration is possible since the sheet is immediately locked on the projections of the male mold.

This type of forming produces a part which has a heavy top section. However there is still excessive thinning on the lower side walls since that section of the mold reacts exactly like a female mold. It is limited to low-profile parts; it is mainly used in combination molds wherein certain sections of the product must be strong and of full thickness.

## Drape Forming Over a Male Mold

Plastic products with thick wall sections may be formed by the drape process without extreme waste. In low-profile work, parts may be formed either by straight vacuum or by the drape process. However, a better product can be formed from a thinner sheet by the drape process. In this process the plastic sheet is draped or pulled over the male form until it is level with the lowest height of the mold. The sheet is then sealed at the edges of the mold and vacuum is applied, pulling the sheet to



Drape forming over a male mold.

the contours of the mold. Parts may have female sections within the male form, thus making it possible to form many complicated shapes.

Pre-decorated sheets can be accurately formed, but closer control of the prestretching is required. The temperature of the mold, the speed of draping, and the accuracy of registration all contribute to the quality of the end product.

The drape process is the most popular at the present time since mold costs are lower compared to female molds, forming and release are simpler, the quality of the end product is superior on deep draws, and since the product is free in the area on the external side, it is easier to cool.

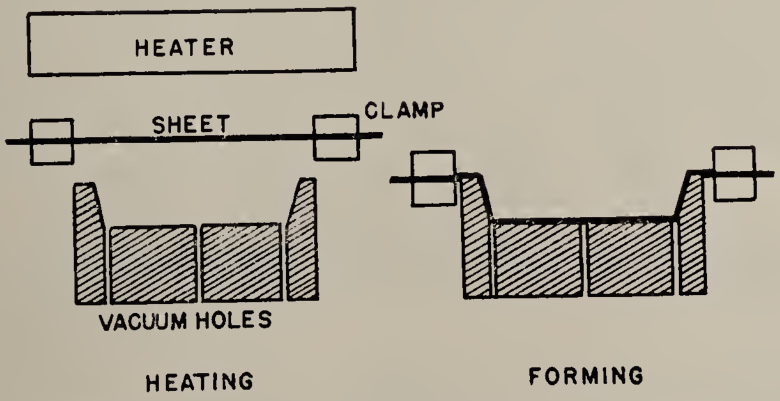
Every field using sheet forming has applied the drape process effectively. A general rule of thumb with respect to design is a one-to-one ratio of depth to diameter. However, with some of the newer deep-drawing materials, such as calendered vinyl, this may be increased to one and a half to one.

In the drape process the heaviest sections occur at the top and the part will thin out toward the bottom of the mold, though not as excessively as it does in the female mold. However, if an item such as a deep tray or pan were made by the drape process, the bottom of the pan would be strong and the edge or lip would be weak due to the thinness of the material.

Among the highly successful users of this process are the appliance manufacturers who form refrigerator doors and interior parts from styrene copolymer of from .060 to .187 inch thick on water-cooled aluminum drape molds. They account for 75 per cent of the styrene copolymer sheet used in sheet forming. The recessed parts of the drape mold must be drilled with vacuum vents to provide proper drawing. However, the over-all mold has few holes as compared to straight vacuum. The usual practice is to mount the male plug or mold on a molding base over a large hole, spaced approximately .010 to .015 inch away, to provide bottom edge venting. The external part, or the part away from the mold, will usually have good surface finish because there is no mark-off. This is the side that is usually the external surface of refrigeration parts. In general, drape forming accounts for the majority of the products now manufactured by sheet forming.

## Drape Molding in a Female Cavity

A variation of the drape process is used in which a means of heating away from the female mold is provided. Some materials such as flexible vinyl, polyethylene, or some of the heavy plastics will droop considerably when heated and lock up on the mold, thus preventing uniform heating and forming.



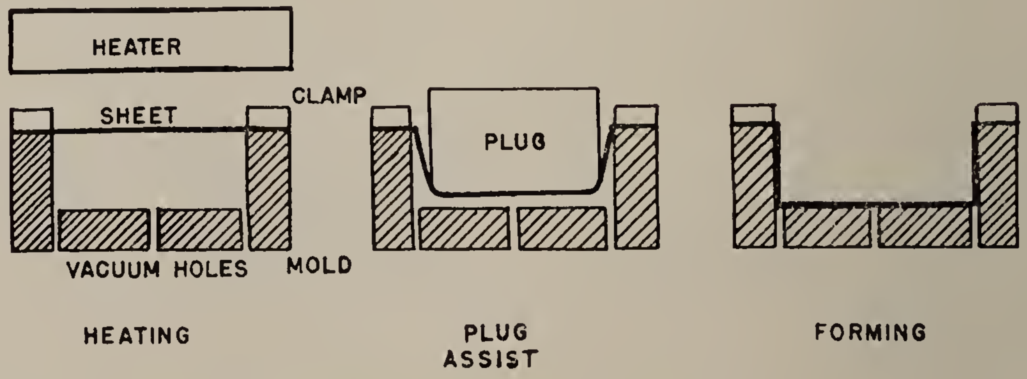
Drape forming in a female mold.

By elevating the plastic sheet during the heating process it is held far enough away so that it will not touch the mold. After heating, the sheet is draped around the edge of the female mold, sealing it off, and vacuum is applied conventionally, pulling the plastic sheet into the female mold. This results in a superior product and provides a stripping action from the female mold.

## Plug Assist and Plug Forming With Vacuum

In examining vacuum forming in a female mold it will be found that the extreme bottom thins out considerably making the part weaker at this point. With drape forming it will be found that the extreme top retains full thickness, but that the side walls thin out. In order to utilize the best features of these two processes a type of forming can be used called plug forming or plug assist.

In the plug assist method a female mold is used, and prior to applying vacuum, a plug is introduced in the cavity forcing the material to the bottom. Vacuum is then applied, pulling the sheet away from the plug and conforming it to the contours of the mold. In this case the plug assist is normally not heated and the final product will have a better distribution since the plug will lock the material to itself, leaving more material at the bottom. Since the vacuum-forming operation only moves the



Plug assist and plug forming with vacuum.

sheet a slight distance, the mold itself may be run cooler, thus decreasing the cooling cycle. This part will, of course, have a heavy section at the bottom and thinner walls, and will not of necessity be good for deep drawing.

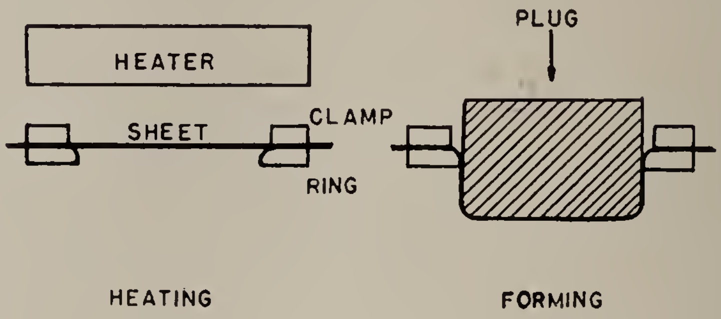
For the more uniform distribution of material required for deep parts the plug must be heated to a high enough temperature so that the material will slip along the plug as it enters the sheet thus bringing the heavy material from the bottom up to the sides. The temperature for the plug in this case must be greater than the temperature at which the material sets, however, the material if left on the plug would never cool. By having the plug close to the final female mold and pulling the material from the plug against the cool sides of the mold, the part may be held in place long enough to cool. The plug is, of course, removed as soon as the vacuum has taken over the sheet. This process requires close control of both the sheet temperature and the plug temperature in order to make accurate parts.

The equipment required is more complex, the molds are more costly, and the temperature of both the mold and the plug must be controlled to close tolerances. However, deeper parts may be formed by this method than with any other method presently available.

The plug enters the sheet at a very fast rate, as much as 30 inches per second, and the materials selected and used must be of uniform caliber and uniformly heated for best results. The plug assist is used in parts not requiring accurate side walls or bottoms and is far simpler to use since the plugs may often be of wood.

## Plug and Ring Forming

In plug and ring forming there is no vacuum or air pressure required. A plug and ring is made with only enough clearance for the material to be formed by the action of the plug stretching the material through the ring. The temperature of the plug should be below the deformation temperature of the material in order for the part to cool on the plug sufficiently so that it will not lose its shape when the plug is removed.

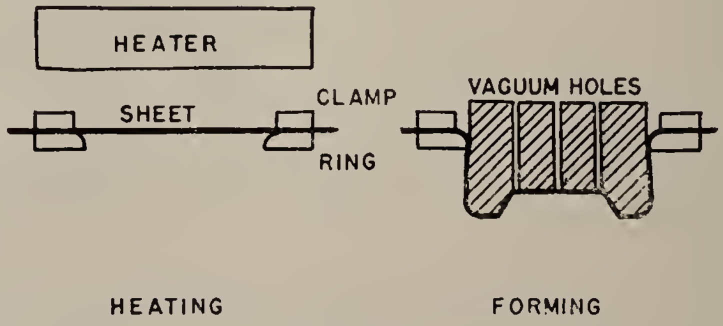


Plug and ring forming.

It is limited in that for best formations the temperature of the plug should be higher to allow material slippage. It can be used extensively for shallower molds, however, and is especially useful on heavy or tough materials where mark-off is not objectionable and where the product has no recesses.

## Plug and Ring With Vacuum

Where the part has recesses or openings, vacuum is applied to the plug of a plug-and-ring arrangement. The process proceeds exactly as in a plug and ring set-up except that vacuum

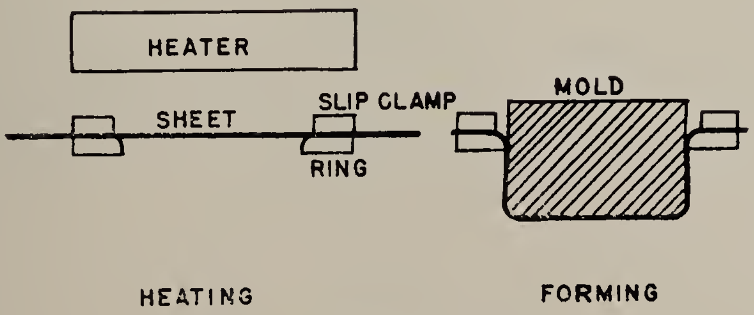


Plug and ring with vacuum.

is introduced into the plug at the bottom of the stroke, pulling the material into the recesses or cavities of the plug. Although this process permits more complicated shapes to be formed, the materials used must be ductile enough to be formed by vacuum and the recesses, which act exactly as a female mold, should not be too deep or too severe.

## Slip Ring Forming

For best results with the plug and ring method the process called slip ring forming is used. In the previously described processes, the deeper parts stretch considerably, resulting in thin side walls. In order to make a stronger part, a plug and ring set-up may be used in which the clamp exerts only a low pressure or the clamping pressure may be released slightly during the plugging action. After heating conventionally, the plastic is held in this clamp and the plug is pushed into the plastic to draw the part. The loosely held plastic sheet will slip under the clamp and draw into the side walls producing a part with thicker walls than would be otherwise possible. Various types of clamping methods have been devised to control this slippage. In some cases it is necessary to heat the clamp to prevent chilling of the sheet. Some people also go to the extent of providing a lubricant between the clamps to insure proper



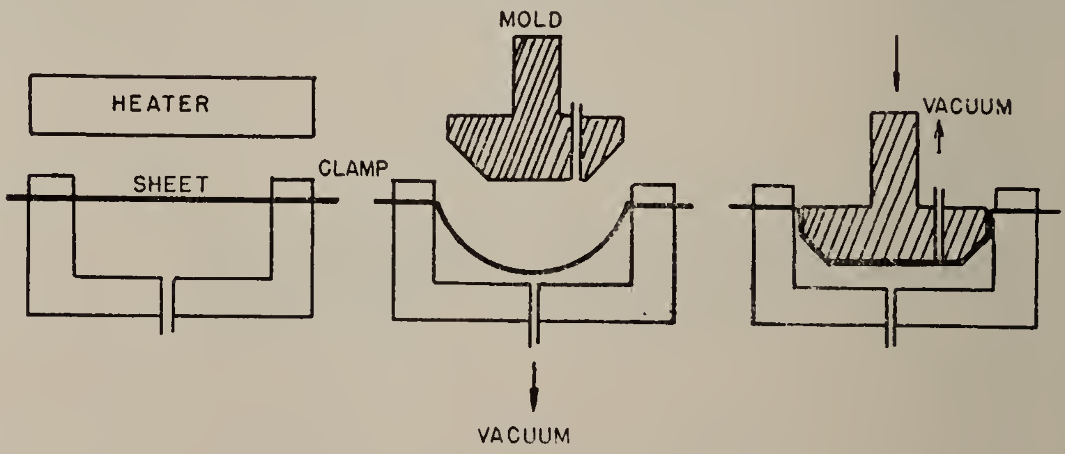
Slip ring forming.

sheet slippage. Again, there will be mark-off on the side walls from the clamp; however, in many cases this may be minute and therefore not objectionable.

## Vacuum Snap-Back Forming

Another variation of forming which is valuable from the point of producing stronger parts with more uniform wall thickness is called vacuum snap back forming. The plastic sheet is clamped on top of a vacuum box and heated conventionally. When the sheet has reached the proper temperature, vacuum is applied to the vacuum box and the sheet is pulled down to a predetermined depth. The male mold or plug is lowered into this pre-formed cavity and sealed on the edge of the sheet or on the edge of the box. The vacuum is then released from the box and applied to the male mold. The vacuum entering the tiny holes in the plug snaps the plastic sheet against the mold, forming it to the contours of the mold.

Some fabricators use vacuum in the vacuum box only. When vacuum is released slowly, the natural tendency of certain plastics is to return to a flat sheet and the sheet settles back against the plug. In this type of forming reverse projections



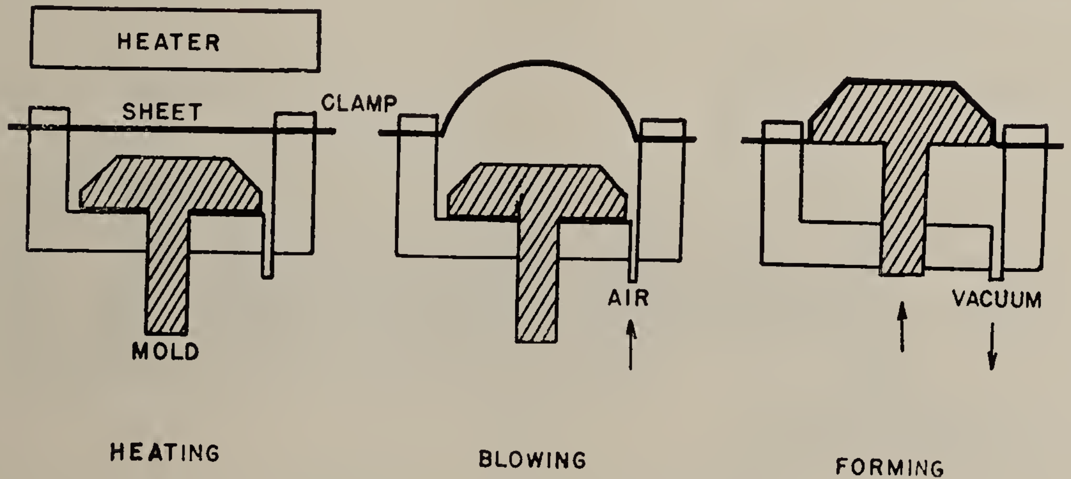
Vacuum-snap back.

cannot be formed. However, very little mark-off occurs so that optical clarity can be maintained.

This type of mold is used in an air press with an overhead piston. However, some of the new plug forming machines may be equipped with a vacuum box to perform this operation on a semiautomatic cycle. In order to form the original vacuum bubble to the correct depth, the vacuum box is equipped with a photoelectric eye set at a predetermined level and connected to the automatic controls of the machine.

## Pressure Snap-Back Forming

Some fabricators prefer to utilize the snap-back process, blowing the bubble upward rather than vacuum forming in a box. This process works exactly the same with the exception that when the plastic sheet has reached the proper temperature, air is introduced into the sealed box underneath the sheet. This pressure blows the heated plastic into a bubble. A photoelectric eye set for the proper height triggers the plug or mold upward. When the mold has reached the seal-off point, the air pressure is released and vacuum is introduced into the mold box, pulling the plastic to the contours of the mold through the many tiny holes drilled in the mold. Conventional up-drape type machines



Pressure snap back forming.

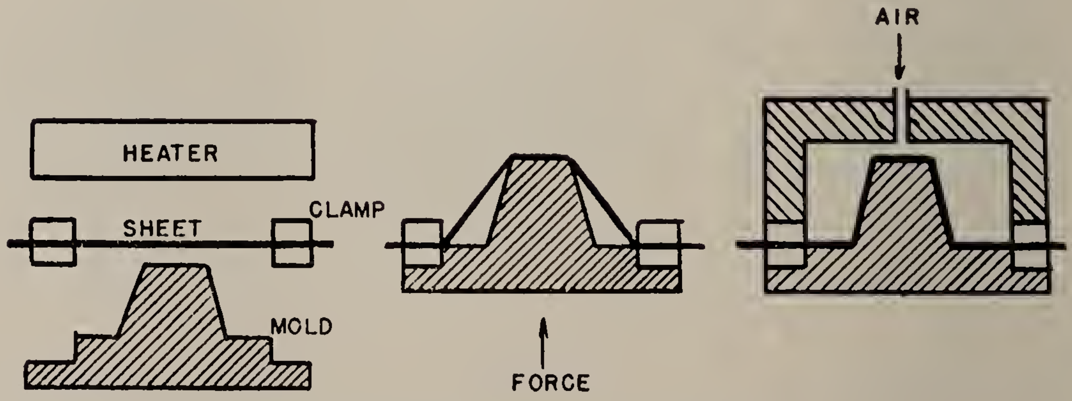
are used for this process. However, it must be remembered that the mold and box set-up are more expensive than the conventional type forming processes.

Usually parts of great depth can be formed by the snap-back process which offers the possibility of forming many products not previously obtainable by conventional methods. The mold construction is the same as used in conventional vacuum forming and may be run slightly cooler since there is less forming or stretching.

## Blow Back Forming With Pressure

To utilize the drape formed process with heavy materials or with materials which cannot be formed by vacuum, air pressure may be used to form the plastic after it has been pre-formed by the drape process.

After heating the plastic in the conventional method, it is draped over the mold in a tent-like formation. At this point a pressure head on an overhead ram descends and seals the clamp frame and material to the mold. Air introduced at this particular point blows the plastic to the contours of the mold. Vent holes must be drilled in the mold to provide passage for the air trapped between the sheet and the mold.



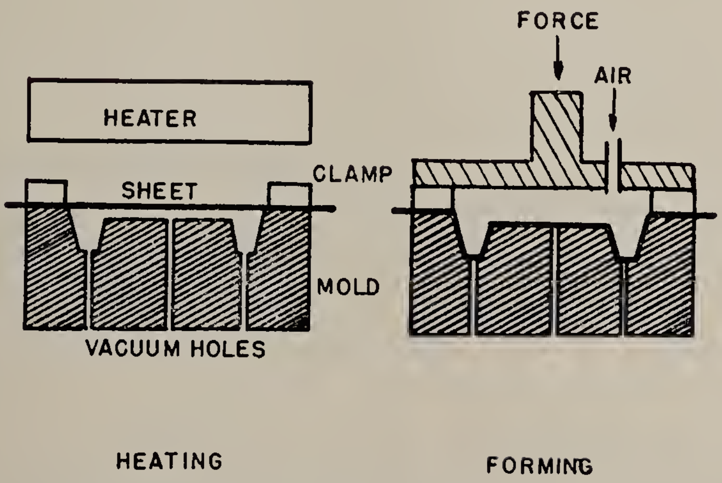
Blow back forming with pressure.

With some of the tougher materials now available this method promises an answer to deeper formations than are possible with some of the other processes. Equipment, however, is generally not available but it may appear on the market in the near future. Products made by this process will have very accurate dimensions, high detail, and they will conform to the mold.

### Pressure Forming in a Female Mold

In this type of forming an hydraulic press is used to clamp the mold against the pressure plate; the clamping must be adequate to resist the impact of the air pressure which may go as high as 300 psi. The plastic sheet may be clamped in a frame and heated externally to the proper temperature, at which time it is transferred to the press. With some of the newer machines, it may be heated directly in place over the female mold. The heater in this case also acts as the pressure plate. After the press is closed, air is applied through holes in the pressure plate forcing the material to the contours of the mold.

Limitations of design are exactly the same as those outlined for vacuum forming in a female mold. However, tougher materials may be formed and the parts will have good dimensional tolerances.



Pressure forming in a female mold.

The molds must be carefully polished since the pressure will pick up any defect in the mold; however, embossing, lettering, and many designs of this sort can be incorporated in the product.

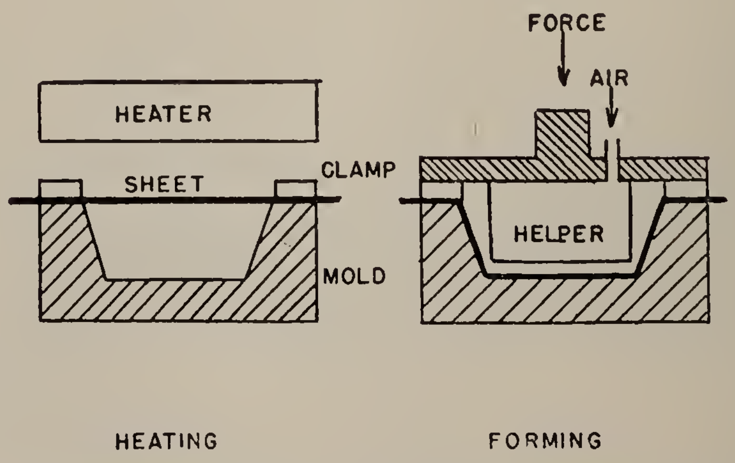
In any of the processes described requiring pressures the equipment is much heavier and, consequently, more expensive. Hydraulic presses with high ram speeds and pressures from 50 to 200 tons are used.

Many of the early flexible vinyl place mats were formed in this way since the high pressures duplicated every detail of the mold to a point where they closely resembled a fabric mat.

While metal molds are generally used to withstand the high pressure, some work has been done with epoxy resin molds with good results. Many of the other mold materials will break down from the high pressures. Care must be taken in making the molds since the pressure will force material into any undercut and lock it to the mold.

## Pressure Forming in a Female Mold with Helper

In order to reduce the thinning at the bottom of a female mold a helper is sometimes mounted on the pressure plate. In this case, heat is applied on the outside of the mold area and

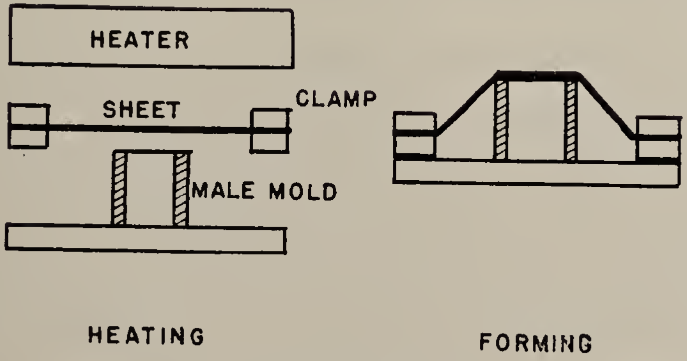


Pressure forming in a female mold with helper.

when the proper temperature is reached the plastic is transferred to the machine and clamped. The plug is introduced which prestretches the plastic and draws material from the side walls into the bottom of the cavity. When the plug has reached the bottom, the pressure plate is sealed off against the clamp and air pressure is introduced which blows the part against the contours of the mold. This process permits deeper parts to be formed of the tougher materials and it is also used for high-profile products. Parts of this sort have good dimensional tolerances and may often be clearer than those obtained by conventional methods.

## Ridge Forming

Sometimes it is possible to have parts which require only partial molds to achieve the desired results. Ridge forming is quite simple, but the parts are limited. The plastic sheet is heated by conventional methods and then the partial mold is pushed into the heated sheet. The material is stretched between the clamp and the partial mold resulting in a formation which has good surface and which may be optically clear since its only contact is with the partial mold. At the point where the partial mold hits the sheet there may be mark-off, but in most

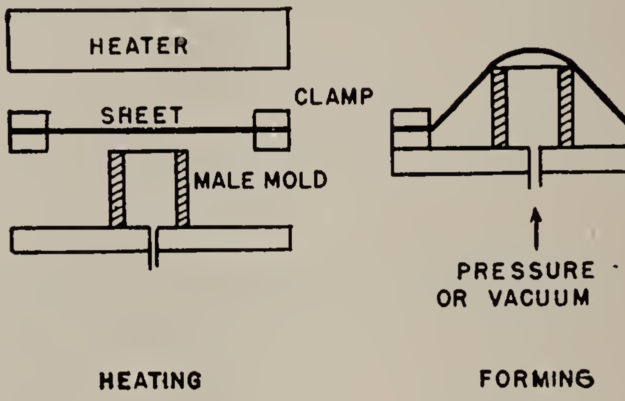


Ridge forming.

cases this is not objectionable. This process can be used as part of other molding techniques to great advantage.

## Ridge Forming with Vacuum or Air Pressure

To permit variations in the ridge-forming technique, air or vacuum may be introduced into a sealed section of the ridge. This would result in a free blowing or free forming section within the ridge formation. Since there is no mold the amount of formation at this point is limited; however, the part formed will have an excellent surface and may be optically clear.

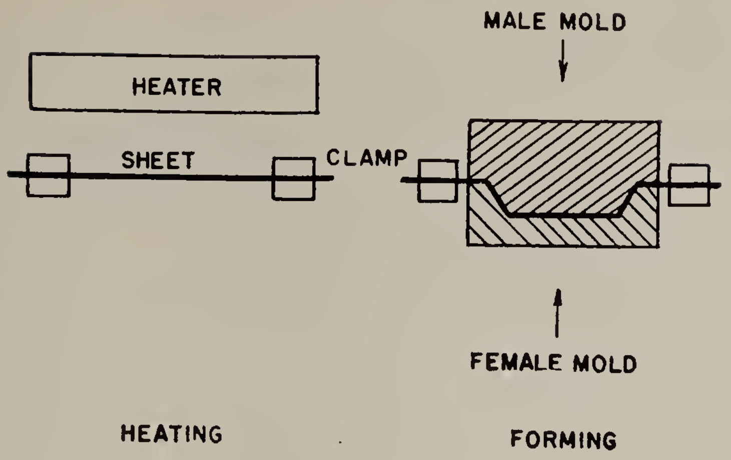


Ridge forming with vacuum or pressure.

This process is not extensively used but it has been valuable in forming "Plexiglas" into decorative items.

## Male and Female Mold Forming

Plastics may be treated exactly as metal for certain products; that is to say, they may be formed in a conventional male and female forming die. In this process the sheet is heated externally and transferred between the male mold and the female mold. Closing the press forms the sheet directly to the contour of the mold. Very accurate parts are produced by this method which also may cut, perforate and otherwise fabricate the



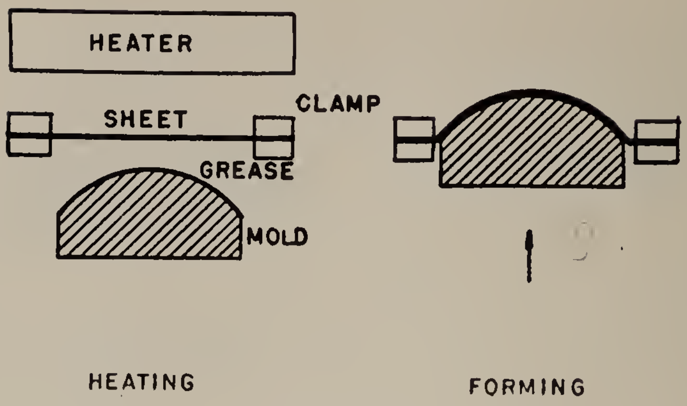
Male and female mold forming.

sheet. The molds must be warm, otherwise the parts will not form properly. Heavy mark-off occurs with the male and female mold but the designs have very accurate tolerances. The depth of draw is limited since the plastic sheet has little or no slipping action. This type of forming is used extensively for the production of small boxes and containers, usually of opaque materials.

## Grease Forming

For the production of heavy guage, optically clear parts a technique called grease forming is employed. This is especially useful in the formation of aircraft canopies where the acrylic plastic must contact the surface of the mold to obtain the desired shape, and yet the finished part must have perfect optical properties.

Grease is applied to the male mold to prevent mark-off. The grease becomes fluid when it comes in contact with the hot plastic sheet, thus the sheet is lubricated and can move freely. The mold is often covered with a felt blanket and the grease worked into the warm mold until it is thoroughly saturated. After the sheet has been heated to the proper forming temperature the hot form is pressed upward into the sheet forming the



Grease forming.

part. It is left on the mold to cool and when removed it is washed with various solutions, such as kerosene or white gasoline.

It is also possible to use this formation with vacuum and pressure in a female mold which has been similarly treated. This process is of course relatively slow since the grease must be re-applied after every formation. The parts produced however are of the highest quality obtainable in the sheet forming industry.

## New Techniques

While the methods outlined here are the extent of the present knowledge in sheet forming, it is possible that additional methods may be available in a short time. However, it should be remembered that these may be combined in the same mold or in sections of the same mold to provide additional forming techniques. A good knowledge of the various techniques will enable one to analyze the product and to make the best selection.

Commercial machinery is being improved every year and it is now possible to buy equipment for most of the above processes. Many of the individual processes may be improved by various techniques, i.e., by shading the plastic sheet during heating more heat will be provided in the center of a drape process and less on the outer sides of a sheet around a single mold. This permits a greater amount of heat on the top of the plug allowing the material to stretch, and less heat on the side walls reducing the stretch, thus resulting in a part with more uniform walls. Introduction of heated clamping frames reduces the cooling effect on the outside of the sheet, permitting more material to be drawn into the side walls, and reduces the heating time required. Introduction of water coils in the mold permits temperatures to be accurately maintained, i.e., styrene copolymer molds should be run at approximately 125° F and molds for cellulose acetate at approximately 145° F, for best results.

Drape assist frames which pull the plastic down around the male molds also increase the side wall thickness and permit formations to be placed closer to each other.

It must be remembered that with many of the plastics available close attention must be paid to their forming characteristics. Obviously, some materials will draw better than others, i.e., vinyl copolymer may draw well on a mold on which a styrene copolymer sheet could not be run, thus the material selection many times will control the type of mold to be used.

A careful study of these materials and of the molding techniques will permit one to judge instantly how the mold should be made and how it should be run for good formations. When in doubt, consult a plastic materials manufacturer; he can instantly make available the characteristics of the material or may even have a special formulation for special types of products or materials to be used with certain forming techniques.

# 4. SELECTING THE PROPER MATERIALS

In no other manufacturing process does one have such a wide choice of materials with which to design the many thousands of parts as in sheet forming. While twenty of the most common basic plastic materials used extensively in this process will be listed here, many other formulations are available. These basic materials may be laminated to other materials, metalized, flocked, embossed or they may be altered by the manufacturer with the addition of special ingredients.

Because of the many variations in the properties of plastic sheet materials, the sheet former should check with the supplier to acquire the exact formulation suitable for his purpose. They are able to furnish the current formulations and prices, as well as such characteristics as:

Outdoor weathering
Light stability
Moisture and dimensional stability
Impact
Tensile strength
Distortion temperature
Electrical properties
Burning rate
Acid effect
Alkali effect

and any other properties necessary for proper coordination between material and product.

The method by which the basic plastic sheeting is manufactured will also be discussed here. This is necessary since not only will the original manufacturing process determine the quality or characteristic of the final product but it may also require a different method of forming. Thus, it is necessary to know just how the material was manufactured, i.e., sheeting made by the cast process is usually more difficult to form but, on the other hand, it has greater optical clarity, resulting in a higher quality product.

Sheeting or film for plastic sheet forming is produced by the following methods:

Compression molding
Casting
Extrusion
Orientation of extruded sheet
Calendering
Laminating

## Compression Molding

Compression molding of thermoplastic sheets is not common. Formerly, one of the chief methods of making sheet, it is expensive since it is a batch operation. The pre-mixed plastic is placed in a press where it undergoes a complete heating and cooling cycle under hydraulic pressure. The output is low and the cost subsequently higher than for most other processes. It is generally used only for heavy guage materials and at present is molded up to 1 inch thick. Materials currently produced by this process are cellulose acetate, cellulose acetate butyrate, styrene, vinyl copolymer, and polyethylene. It is generally used for special projects. The size of the sheets produced is limited.

## Casting

Fabrication of cast thermoplastic sheet produces a high quality material, usually somewhat harder than that obtained by the other processes since it requires little or no plasticizing.

Casting is one of the oldest methods of sheet production. In one of the block methods the material is polymerized to a viscous syrup, and mixed with a sufficient amount of a catalyst for subsequent polymerization. The syrup is then run into a mold, which is heated by a hot-water bath, and the cast form solidifies. The materials made by casting are limited only by the size of the mold; parts can be cast up to 3 inches thick. Since there is an absence of strain, crystal clarity is obtained in some materials.

For thinner sheets the block may be planed, slicing off sheets of the desired thickness, although now the material is usually cast to size. The casting process varies with the materials though basically the procedure is the same. Sheets may be further processed to remove the residual solvents and polished by pressing them with highly polished platens.

Thinner films may be cast directly on a metal belt which has been heated, or by one of the newer processes, or they may be cast on paper. In this process the plastic material, in soft form, is scraped off the rolls in the desired thickness (as little as .0007 inch thick) on a moving belt where it is heated and sets before it reaches the end of the belt. This method of producing film is much faster than the block form and subsequently, far less expensive. Slightly thicker materials are produced by casting on a heated drum as large as 20 feet in diameter. The material is measured off on the outside of the heated drum by a doctor blade to the proper thickness. It stays in contact three-quarters of the way around the drum which is sufficient to set the material.

Materials processed by casting are:

1. Flexible vinyl film used for skin packing
2. Cast acrylic
3. Cellulose acetate
4. Cellulose acetate butyrate
5. Cellulose nitrate

*Cellulose nitrate* is not used extensively in sheet forming because of its high flammability, although it was the first sheet available and was extensively formed by means of steam.

*Flexible vinyl film* is extensively used in packaging, especially in skin packing where its high strength, clarity, and lack of strain make it a vital material.

*Cellulose acetate* and *cellulose acetate butyrate* cast sheets have not been used extensively in sheet forming due to the fact that they are more difficult to form than extruded film; however, some of the newer techniques such as pressure forming have produced excellent products from these films. They have many advantages such as a high degree of clarity and translucency and greater strength.

*Cast acrylic* is one of the most valuable materials and many millions of pounds are used annually. It is usually cast between glass plates which produce a beautiful, crystal-clear material. It is used for aircraft canopies and windows, lighting fixtures, outdoor signs, and for many other high quality products. It is difficult to form and requires special equipment due to its high strength.

## Extrusion

More material is produced by extrusion than by all the other processes combined. The reason for this is that it is a simple method of producing sheet, and many sheet formers install their own extruders, thereby reducing their material cost. By installing these they can also re-use the scrap and do not have to make allowances for this in their cost.

Basically, the material is fed into a hopper in pellet form where it is pre-heated and dropped into a screw affair which forces it through a heated barrel and then through a die at the opposite end. The die is of the proper thickness and width desired. Generally the sheet is produced from .010 to .250 inch thick. Extrusion equipment is measured by the diameter of the screw. The extruders range from 2½ to 8 inches and the pounds produced per hour depend on the thickness, i.e., a thinner material produces fewer pounds per hour. For example, a good output on a 4½ inch extruder would be approximately 400 pounds per hour of styrene copolymer.

After the materials are extruded they are either rolled on a paper core or cut into sheets. Other attachments may be used on the extruders to perform such operations as laminating another film to the material, glossing the top of the sheet by heat, or embossing a design in the sheet. Extruded sheet is less expensive than sheet produced by some of the other processes but it may have greater variations in thickness; it may also have extrusion lines or flaws. These slight defects however are acceptable in vacuum forming products. Materials produced by extrusion are:

Cellulose acetate
Cellulose acetate butyrate
Polyvinyl chloride
Styrene copolymer
Straight styrene
Styrene blend
Polyethylene, both standard
  and linear
Acrylic
Nylon

## Orientation of Extruded Sheet

Orientation after extrusion is another process which produces sheeting with unusual characteristics. In this process the material is biaxially stretched under accurately controlled diameter conditions. This two-directional stretching results in an increase in tensile and impact strength so that extremely thin guages are sufficiently tough to be used in place of much heavier plastic sheeting. Only thin sheets from .0025 to .020 inch thick are produced by this process. Materials produced by this method are:

Oriented styrene
Oriented acrylic
"Mylar"

The actual production figures of "Mylar" are not known.

## Calendering

In this process the material goes through a series of heavy rolls. It is generally used for thinner guage sheets. Calenders are expensive, costing as much as $300,000 each; however, they produce a high poundage of sheet per hour. Although high pressures are required to form the material the thicknesses of the sheets are very accurate. This makes the sheet forming operation easier since the material reacts uniformly and deeper drawing can be accomplished. Materials produced by calendering are:

Flexible vinyl
Vinyl copolymer
Polyvinyl chloride
Styrene blend

In general, the finishes are not as good as those obtained by some of the other processes but calendering has a wide range of possibilities and it produces materials with high strength characteristics.

## Laminating

Calendered materials may be formed into many thicknesses by placing them in a hydraulic laminating press and applying heat and pressure, thus thicker materials, or materials with special properties can be obtained. There are also laminating machines whereby this is done on a continuous basis; however, these are not too common. During the laminating process an embossed grain may be made on the top of the sheet. Materials made by the laminating process are polyvinyl chloride and styrene blend.

Other possibilities are laminating “Mylar” film to styrene copolymer, or “Mylar” to flexible vinyl. This field is still being explored. The possibilities of laminating are enormous since a material with a high gloss or one having special abrasion resistance may be used on the top and an inexpensive material on the bottom, forming a part which has a durable surface and at the same time is inexpensive.

## Materials for Sheet Forming

As we pointed out earlier, there are many plastic materials available to the sheet former. To evaluate each of these is a considerable task, since each material may be produced in sheet form by many different manufacturers and by several different processes. There are also many formulations of the same material, thus the forming characteristics and the physical characteristics of the material vary widely. It is hoped that in the future the standards for the various materials will be more closely aligned to sheet forming requirements.

There are also new materials appearing every year which hold promise for the sheet former. Some of these are designed for his specific needs and may make it possible for him to produce a greater volume of products at a lower cost. Other materials will give him an entry into fields not yet penetrated by sheet forming.

Following is a list of materials generally used by sheet formers:

*Acetates*
- Cellulose acetate (extruded and cast)
- Cellulose acetate butyrate (extruded and cast)

*Vinyls*
- Flexible vinyl (calendered)
- Flexible vinyl (cast)
- Vinyl copolymer (calendered)
- Vinyl copolymer (press polished and laminated)
- Polyvinyl chloride (extruded)
- Polyvinyl chloride (calendered and laminated)

*Styrenes*
- Polystyrene copolymer
- Straight polystyrene
- Oriented polystyrene

*Styrene Blend*
- Copolymer acrylonitrile—styrene extruded
- Copolymer acrylonitrile—butadine—styrene calendered

*Polyethylene*
- Standard polyethylene
- Low pressure or linear polyethylene

*Acrylics*
  - Cast acrylic
  - Extruded acrylic
  - Oriented acrylic

*Specials*
  - "Mylar"
  - Cellulose nitrate

**Cellulose Acetate.** Cellulose acetate is one of the oldest materials produced in sheet form. It made its appearance around 1912 primarily as a material for photographic film to replace the highly flammable cellulose nitrate. It is the most common material now used for packaging because of its clarity, reasonable cost, and ease of fabrication; it is also used for displays, toys, and novelties.

When sheet forming came of age several years ago, cellulose acetate was not extensively used since the available formulations were too difficult to form by vacuum pressure. The newer formulations designed especially for vacuum forming were instantly accepted and are now used for the majority of blister packs, two-piece packaging, containers, etc. It is available in both cast and extruded forms ranging in thicknesses from .0005 to .250 inch. The thinner guages are available in rolls and can be used in the newer automatic roll feed-type of machine, thus making it inexpensive to form. It also has a wide range of transparent and opaque colors. It has good impact resistance and a reasonably hard surface. It is generally not used for outdoor applications due to its high moisture absorption. Recent advances in machinery using pressure make it possible to use the older and harder formulations which give promise of even stronger products.

**Cellulose Acetate Butyrate.** Cellulose acetate butyrate sheeting has also been available for some years. However, its original method of production was expensive. Recently, however, it has been manufactured by the extrusion process, which has lowered its cost considerably. It has many excellent properties, and is available in thicknesses from .0007 to .250 inch. It has excellent forming characteristics and can be formed in a very deep draw. Some formulations are excellent for outdoor applications such as signs, etc. It has a low moisture absorption rate. Its excellent impact resistance makes it applicable for toys, displays, heavy packages, housings, helmets, skin packing and transparent packaging.

Like cellulose acetate, it is available in various transparent and opaque colors, since it is one of the most easily formed of the materials. It is often selected for more difficult parts, even in preference to the less expensive materials.

**Flexible Vinyl (Calendered).** Flexible vinyl has been extensively used for such items as raincoats, shower curtains, and table cloths, in which the basic material is roller embossed after calendering. However the designs made by this method are shallow, and in the search for heavier embossing many people turned to sheet forming. Many items such as place mats, bath mats, wallets, book binding covers, and inflatable toys have been produced by vacuum forming. There is also a good market for vacuum-formed sheeting in which plain sheeting is run through a vacuum machine to produce a deeply formed sheet. This type of sheet is used in the handbag and shoe trade and in the automotive field for the production of interior door panels and trim. Some of the new developments in this field proposed using formed vinyl sheeting for seat parts and floor covering.

It is generally available from .004 to .040 inch thick. It is quite inexpensive and can be obtained in clear transparent to brilliant opaque colors. Many millions of pounds are used annually for place mats alone.

**Flexible Vinyl Cast Film.** Cast flexible vinyl film is extremely thin, ranging from .002 to .008 inch thick. Its main use in the sheet-forming field is for skin packing. Since it is a cast film it has little stress and when formed it does not tend to curl the skin pack card. It has excellent clarity, is extremely strong, and has good abrasion resistance. It is presently produced only in the clear film although colors can be made. It is more expensive than the flexible calendered vinyl.

**Vinyl Copolymer (Calendered).** This is one of the most popular plastic sheeting materials now available. When produced by calendering it has extremely close dimensional tolerance and stability, making it ideal for applications requiring deep drawing or pre-printing. It is used extensively for signs and displays, Christmas decorations, toys, lighting, premiums and novelties, military maps, and food packaging. It is available in a variety of colors, but not as a transparent sheeting. It is about the same price as cellulose acetate though in some thicknesses it actually costs less. It ranges in thickness from .002 to .040 inch. The thicker sheeting has some tendency toward roughness so printing must be of the rotogravure or offset type. Silk screening is easily accomplished on this material and the paints are durable, abrasion resistant, and retain their colors well in displays and decorations. Its biggest advantage of course is in pre-printing since it will form with perfect uniformity throughout an entire production run.

Vinyl copolymer is press-polished to obtain a clear transparent sheet since it is not transparent in its calendered form and has a slightly matte finish. When press-polished it is a beautiful clear material ideal for displays, packages, and premium parts. It has ideal characteristics for food packaging; however, its higher cost has slowed its development in this field.

Press polished vinyl is easily formed and can be laminated to itself to obtain heavier films. It ranges in thickness from .002 up to .250 inch. It has excellent dimensional stability and therefore can be used for precision dials and measuring parts.

**Polyvinyl Chloride (Extruded).** In the search for a clear transparent film for food packaging, extruded polyvinyl chloride has great promise. Its development has been slow because it is extremely difficult to extrude. Present indications are that this difficulty has been completely overcome and that it will soon be available in all thicknesses. Present thicknesses range from .010 to .030 inch. It is easy to form, extremely tough, resistant to many acids, and quite rigid. It is believed that this particular material will find extensive use in the near future.

**Polyvinyl Chloride (Calendered and Laminated).** This material has been available for some time. It is generally made by calendering .015 inch thick material and then laminating it to produce sheets up to .500 inch thick. It is an extremely tough, high-impact material suitable for outdoor use. It has extreme corrosion resistance, is unaffected by most common household alkaline cleaning solutions, and is stain resistant to most foods. It will withstand petroleum oils and greases. It has been used for such applications as outdoor boat parts, flues, developing tray's, machine housings and, in general, parts requiring great strength and resistance to abuse. The surface may be grained or embossed and such detail will be retained throughout the forming process. It is available in translucent to opaque colors, in many durable formulations. Its price range is considerably above that of the acetates and vinyl copolymers; however, it is a premium material of high strength and durability.

**Styrenes.** The styrenes are the lowest cost group of materials available at the present time for sheet forming. This is due to two factors:

1. The low specific gravity, approximately 1.05, which means that there is more square inches per pound of this material than for all others, except polyethylene.
2. It is easily produced by extrusion.

As pointed out earlier, many sheet formers extrude their own styrene copolymer sheet. Its annual usage for sheet forming exceeds all other materials.

It has several different forms, as follows:

*Polystyrene Copolymer.* This material is the real work-horse of the sheet-forming industry and it is used in practically every field—appliances, lighting, signs and displays, industrial items, toys, household, premium and novelties, and packaging. As pointed out previously, there are many parts formed of the heavier guages (.080 to .125 inch). It is available from .010 to .250 inch. It has good strength and good abrasion resistance to cleaning solvents, making it an ideal material for appliances. It is easily formed by most of the methods and can be used for limited outdoor applications. It has good color; however, it has a tendency to have a dull surface. This has been improved recently by providing a glossing unit to the extruder or by laminating a thin film of oriented styrene to the surface while it is being extruded. It is not as good for deep-drawing applications as some of the other materials. However, its low cost combined with its high strength makes it useful in most fields. It is not available as a clear material; however, some formulations have been made in a translucent form for lighting applications and for illuminated displays. With proper control of the extrusion process a material can be obtained that is good for pre-printed work. It has many applications in the packaging field, such as bases for two-piece containers, and in the display field for brassiere forms, girdle forms, display racks, counter holders, etc., since it may be decorated easily or may be obtained with wood grain finishes. Its use has been growing steadily and it retains its leadership over other materials.

*Straight Polystyrene.* Straight polystyrene is a low-cost sheet forming material ranging from .040 to .125 inch thick. It is not produced in thin guages since it is extremely brittle. Its greatest use is in the field of lighting panels and illuminated products where it is produced as a high-heat resistant material.

Although it is of high strength it is fairly brittle and requires careful handling.

*Oriented Polystyrene.* As already pointed out, polystyrene copolymer is not available as a clear transparent material and straight polystyrene is too brittle to be made as a thin material; therefore, oriented polystyrene which is extruded and bilinearly stretched to obtain high strength and clarity fills the gap between these two materials. It is a low-cost film, being only slightly more expensive than styrene copolymer, but it has high strength and can be made in guages as thin as .001 and up to .020 inch. It is ideally suited for such items as lighting, as a laminate to provide gloss to polystyrene copolymer sheet, for signs and displays, premium and novelties, and packaging. Its greatest drawback is that it is not easily formed by vacuum and generally requires pressure. Roll feed machines utilizing this material have recently appeared on the market. It has a great potential, especially for low-cost packaging.

*Styrene Blends.* Styrene blends are high-strength materials used for industrial applications and applications subject to abuse. One blend consists of a copolymer of acrylonitrile-butadiene-styrene, and is known by some people as an ABS material. It is calendered in .010 to .015 inch thick sheet, and laminated to the desired thickness (up to 1.000 inch). It has high strength and is used for automotive applications, appliances, signs and displays, counter displays, industrial items, toys, aircraft, military, household, premiums and novelties, and packaging. Its cost is almost double that of styrene copolymer; however, it has many desirable characteristics. It is more difficult to form and frequently requires a better type of equipment than used for straight vacuum forming. It can be obtained with graining and leatherette finishes. It is available only as an opaque sheet but can be obtained in any color or with any surface finish. It is good for outdoor as well as indoor applications and has good corrosion resistance. It replaces metal in many of its applications.

*Copolymer of Acrylonitrile Styrene Extruded.* The ABS blend has many desirable features but the tendency is to use it in applications where high strength is required. Its price, however, has been a drawback and since it is either made by calendering or by laminating, price reductions are limited. A new material now on the market is an acrylonitrile styrene blend made by extrusion. This is not quite as strong as the ABS mixture, but its price is 30 per cent less. It is expected that it can be used for many of the same applications as the ABS blend and that it will find many new uses because of its lower cost. It can be obtained in transparent to opaque colors and it is expected that it will be available with grains or leatherette finishes which can be retained throughout the forming cycles. Present thicknesses are from .030 to .187 inch. This material has been identified as "Cycolac."

**Polyethylene.** Polyethylene is one of the lowest cost materials available for sheet formers. Its price is comparable to that of polystyrene copolymer; however, its use for sheet forming has been slow. Although it is difficult to heat and to cool, forming has not proved too difficult and sheet forming techniques have been worked out so that good parts can be manufactured on standard machinery. Yet applications have been relatively few. Some applications such as packages for cottage cheese, end pieces for venetian blinds, shipping caps for threaded parts, etc., have been very successful and economical. One of the best applications to date is the 55-gallon drum covers and liners made by sheet-forming, usually of ⅛ to 5/32 inch material. Test applications are numerous yet actual production is rare. It is hoped that this particular material will take hold in the next few years since its properties are excellent. It is available in many thicknesses from .001 up to ⅜ inch. Colors are available; however, they tend to be pastel rather than solid. It has one drawback in that it is not clear or transparent but rather a milky translucent.

*Low-pressure or Linear Polyethylene.* A new development which holds great promise for sheet formers is the use of linear polyethylene. This exhibits the same characteristics as regular polyethylene except that it is semi-rigid instead of semi-flexible. With the low cost of polyethylene, a rigid, high-impact material would have great success in sheet forming. Original colors tested indicate much more brilliant or solid colors than have usually been experienced with regular polyethylene. So far difficulty has been experienced in forming due to the fact that it is also hard to heat and to cool. Various techniques of sheet forming have been worked out and indications are that double-sided heating will reduce the heating cycle. At present it is used for containers and packages in the food industry. The thickness range is the same as for straight polyethylene (from .001 up to ⅜ inch) and the costs are relatively the same. Care must be taken in preparing the mold since it has a high shrinkage rate of .020 to .040 inch per inch.

**Acrylics.** Cast acrylic sheet is one of the costliest materials, yet it ranks second in the quantity sold per year. It is a high-quality material used for aircraft canopies and windows, large outdoor signs, lighting, automotive, appliances, signs and displays, industrial applications, and packaging. It ranges in thickness from .060 to 3.000 inches. It has excellent properties of high strength and optical clarity. It is made in many formulations—one for outdoor weathering and another for use in fluorescent lighting for which it is made resistant to heat and deterioration from ultraviolet.

It is difficult to form on most standard machinery since its high strength requires greater pressure than afforded by vacuum. Many of the applications which are of simple design however can be formed with standard equipment. It is available in all colors from clear transparencies to opaques and it has a brilliant luster. Its cost however is among the highest on the market.

*Extruded Acrylic.* To obtain the properties of cast acrylic at a lower price one must turn to the extrusion process. While of lower strength it still retains many of the desirable properties such as outdoor weathering, ultraviolet resistant, transparency and brilliant coloring. However, it does not have the brilliant optical surface of cast sheet since the extrusion process leaves fine lines and surface defects. These are not noticeable in many applications and usable parts can be manufactured. Its range of thickness is from .040 to .125 inch; however, its cost is only about 60 per cent of that of cast acrylic. It is far easier to form than cast acrylic and most any conventional machine can be used.

*Oriented Acrylic.* Oriented acrylic is an extruded material which has been biaxially stretched to obtain high clarity and high strength in thin guages, since cast and extruded acrylic are too brittle. Its main use to date has been for the panel lighting work such as entire ceilings made of plastic. It has excellent weatherability and dimensional properties, and its price is somewhat between extruded and cast acrylic. It is only available from .015 to .020 inch thick. It is generally produced in a translucent white; however, its color range is unlimited, from transparents to opaques.

**"Mylar."** "Mylar," an oriented polyester film produced by the duPont Company, is available only in thin guages (from .00025 to .0075 inch). It costs approximately $2.25 per pound, and to date it has been made only in the transparent form. It has exceedingly high strength which means that a considerably thiner film or sheet can be used to provide a rigid part. Its use has been limited since it is very difficult to form; it requires high temperatures to form although it sets very readily. Its formable range is quite narrow, thus close controls are required. It has excellent electrical characteristics which make it suitable for industrial applications such as liners or as covers for TV tubes, diaphrams for radio speakers, and for skin packing. Its development has been slow because of inadequate equipment. However, this has recently been overcome and it is believed that there will be considerable activity in this field.

**Cellulose Nitrate.** Cellulose nitrate was one of the earliest sheet-forming materials, but its use has declined due to its flammable nature. Generally, it had been formed by steam or hot-water types of equipment. It is not recommended for use on standard sheet-forming machinery and applications must be carefully checked with Local and National Safety Laws. The use of this material is not generally recommended.

**Other Basic Materials.** Other materials which have had experimental runs are ethyl cellulose, nylon and "Kel-F." While this, by no means, is the end of new materials, since the sheet-forming process is gaining so rapidly many new materials will become available in the near future.

Ethyl cellulose originally appeared several years ago but was taken off the market for military use. It has only recently been returned for civilian use so there is still a limited supply available. Indications are that it will be a high-strength material for packaging since it has a low specific gravity, meaning a good yield. It has brilliant clarity and forms well; however, some of its properties are quite critical and require special equipment. Its resistance to acids and alkalies is good which should make food packaging a possibility.

Nylon has also been tested for its sheet-forming characteristics. It has been found to form fairly easy though there are limited quantities available for test work. Indications are that it will be a rigid, thin material which can be used for packaging. In Europe, a nylon package for fish made by sheet forming has recently appeared on the market. Until more of this is available, exact properties are not too clear.

"Kel-F," which is a high temperature material, has also been sheet formed for some military applications. Its extremely high price has eliminated applications and test work. Present indications are that the heating cycles will be extremely long; however, cooling times are reasonable. All test work was done on thin guage materials.

## Laminates

In order to provide plastic material with the desired properties, many material suppliers have turned to lamination or the bonding together of two dissimilar sheets by heat and pressure or by adhesive action. The purpose of this is to provide an economical material which will have the properties of a more expensive material, or which will provide some special result.

A good example of this is the lamination of a thin film of oriented styrene to a thick sheet of styrene copolymer. The sheet of oriented styrene is only .001 to .002 inch thick and is laminated at the time the styrene copolymer is extruded. This provides a hard glossy surface to the vinyl copolymer sheet for use in the appliance field for refrigerator door liners and interior parts, and in many other display or consumer items where this property is desired.

Another item which is receiving a lot of attention at present is the lamination of metalized "Mylar" to flexible vinyl for automotive interior trim. This provides a hard, durable, bright metallic surface, yet pliable, due to the flexible vinyl so that it may be bent or formed around corners or exactly as fabric.

## Coatings

The most popular form of coating is metalizing in which a plastic sheet or roll is given a bright, hard coating in a vacuum chamber by vaporizing a metallic silver or aluminum. This coating is then color coated with heat resistant dies to give bright metallic finishes. While any thermoplastic sheeting may be metalized, cellulose acetate and cellulose acetate butyrate are the most popular for sheet forming. The best metalizing is done on a cast sheet which gives a smooth sheet with a perfect surface; however, a lower cost sheet is provided by extrusion, but this usually has some surface defects due to the process itself.

In forming the metallic sheets it is necessary to heat them on the opposite side because of the high reflectivity of the metallic surface. Cellulose acetate butyrate draws at a lower temperature when metalized but does retain more of the original brilliance than cellulose acetate. The sheets may be preprinted or silk-screened exactly as if they were not metalized. There are many displays, signs, toy parts, picture frames, product duplications, medallions, and similar parts made using metalized sheets.

One of the newest products available are sheets which have been flocked after extrusion. When formed these produce a beautiful contoured piece with a velvet-like covering; they are used extensively for displays, packages, platform packaging, etc. They are available in any thickness.

To date flocking has appeared mainly on styrene copolymer because of its low cost. The plastic is usually the same color as the flock so that color differentials do not show up when formed. Indications of cost of the thinner guages are that the flocked material is double that of the plain plastic sheet.

Grain or leatherette effects have been available for many years on the polyvinyl chloride and styrene blend materials. These are put in at the time of lamination and are set at a higher temperature than is required for the forming operation. This permits deep drawn parts to be formed without destroying the grain. Graining has also been used on styrene copolymer and flexible vinyl. The grain in flexible vinyl however tends to disappear in most forming operations. These grained materials have extensive applications for automotive interior trim, luggage, displays, aircraft parts, and packaging.

One of the most economical display materials presently available is pre-printed with a design such as wood grain. When formed these materials produce beautiful display racks, packages, and furniture parts, since the graining is retained throughout the forming process. While any material may be decorated in this way, styrene copolymer, which has been colored with a walnut, maple, oak or mahogany type finish has largely been used to date. The material has been made in thicknesses from .010 to .187 inch. The advantage of this type of forming is that once the object is put in the forming machine it emerges as an attractively decorated three-dimensional part. The cost is comparable to other decoration costs and does not appreciably alter the over-all product cost.

# 5. MOLDS AND MOLD DESIGN

One of the chief reasons that sheet forming has advanced so rapidly and proved so economical is its low tooling cost. Since sheet forming molds are in most part one-sided, the one part, either male or female, forms the entire mold. Because of the unique mold construction and the materials from which molds are made, slight product design changes are easily accomplished without making new molds. The quick tooling time enables full production to be attained within several days after the first pilot model is made.

A complete knowledge of mold design and mold construction is essential for successful sheet forming operations because of the following reasons:

1. There are not many sheet-forming mold makers and while some of them may be excellent they may be too far away for the close liaison work required.
2. The sheet-forming field is noted for its speed and the tooling time allowed is accordingly far shorter than for any other industry.
3. Most sheet-forming products require some testing and development so that the final mold is made at the time of the pilot run.

Most sheet formers have their own model and mold-making departments. They do more work in the initial development of products than is done in most other industries; the sheet former actually produces a product in accordance with many of his own requirements rather than one which is completely designed by someone else. Thus he must stay close to the mold design to make the necessary changes and to perform the testing before final production.

As noted previously, both male and female molds are used in this process. The selection depends entirely on past experience and on the process selected. Generally a part drawn in a female cavity cannot be as deep as one drawn over a male mold due to the thinning which takes place at the bottom of the cavity. A good rule of thumb is not to consider female parts if the depth of any section is more than half its narrowest width. On the other hand, male molds using the drape process are highly successful with the height equal to the narrowest dimension.

Plug forming enables deep drawn female parts to be manufactured by fusing material into a female mold by means of a plug before applying vacuum. Successful parts have been made with depths up to twice the narrowest dimension using this process.

## Materials

The type of material selected for the mold will depend on:

1. The number of pieces to be produced.
2. The time allowed for making the mold.
3. The type of materials to be used on the mold.
4. The speed of production required.
5. The size of the mold.
6. The quality required from the finished part.

Mold selection is also very important. At present, molds are made from the following materials:

1. Wood
2. High strength gysum plaster
3. Plastic
4. Sprayed metal

5. Cast aluminum
6. Electroform molds
7. Machined metal

The above materials are also relative in price, the first ones being the least expensive. However, it is difficult to make a hard and fast rule since the complexity of the part or other factors may affect the costs considerably.

## Wood Molds

Wood molds are generally made from a hard wood which has a tight grain. Mahogany and cherry have been used to great

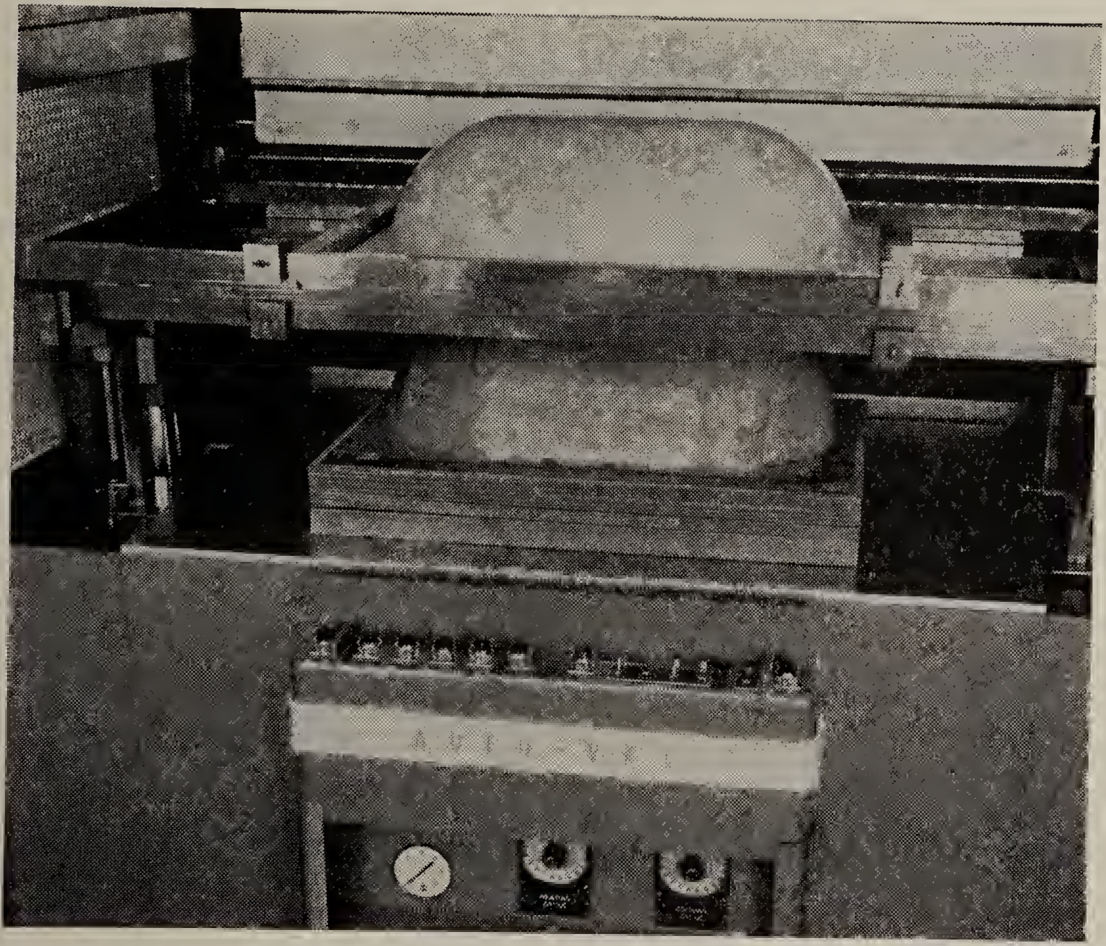


Figure 5–1. Forming on a wood mold by the drape process. The wood mold shown here is made of mahogany coated with an epoxy resin. It is approximately 6 in. high, 12 in. wide and 24 in. long. The material being used is .080 in. styrene copolymer sheet; the heating cycle was approximately 30 seconds with an over-all cycle of approximately 75 seconds.

advantage. When making pilot tests, however, most any wood can be used. However, when woods have not been properly dried, the pressure exerted by the vacuum will squeeze the sap out of the wood, forming an adhesive which grips the plastic preventing separation.

Wood molds have been known to give production runs up to several thousand pieces. Several different types of coatings have been recommended to seal the wood and improve the surface. Some people recommend several coats of phenolic varnish—others recommend several coats of an epoxy resin which has been diluted to a very watery consistency with methyl ethyl ketone.

Wood molds are inexpensive because of the ease of fabrication and low cost. However they have a disadvantage in that they tend to distort or shrink from heat and they are also vulnerable to splitting or breaking, particularly at the corners and edges. Metal reinforcing edges have been used to prolong the life of a wood mold.

Wood molds have been used for displays, toy automobiles, industrial parts, and generally for short production runs.

## Plaster Molds

Although many people may deride the use of plaster molds the fact remains that they are an integral part of sheet forming. Millions of parts have been produced using plaster molds and many more are now in full production. Plaster molds have an advantage in that they are inexpensive, easily made, easily changed and can be reproduced from a formed plastic part. They have several disadvantages in that they are heavy, crack easily, do not reproduce detail perfectly, and they retain heat and are hard to cool. In selecting a high-strength gysum plaster it is important to select one that has zero shrinkage or else it will be difficult to remove from the original model.

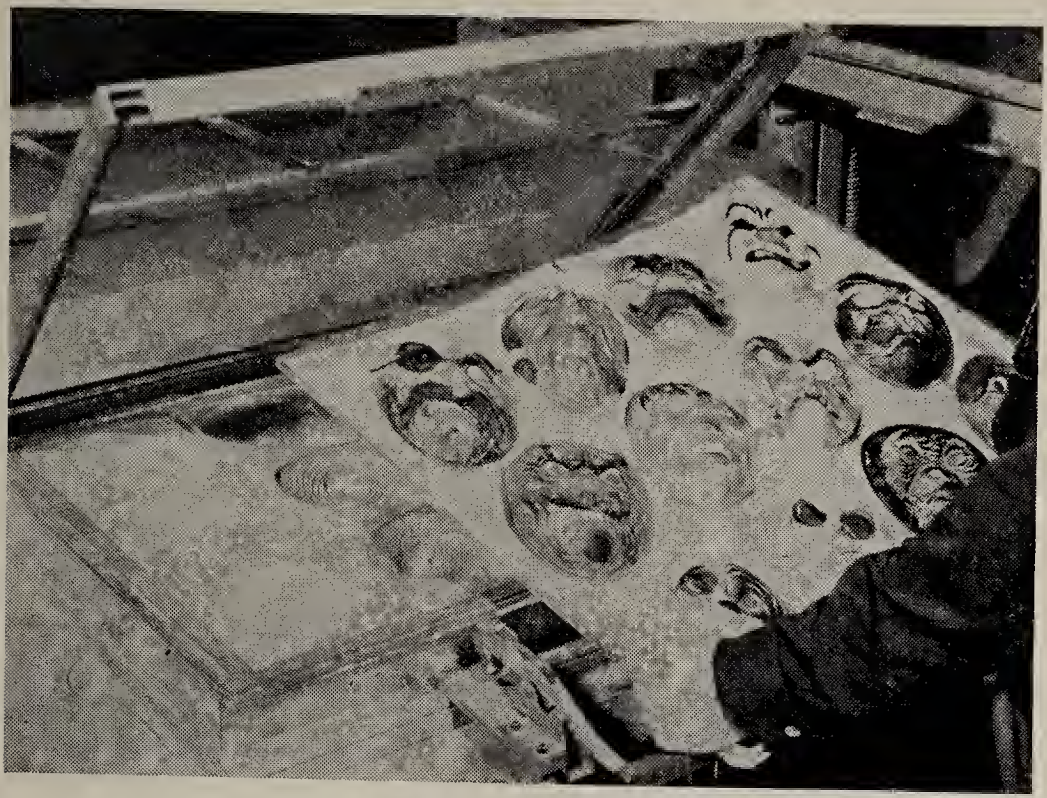


Figure 5–2. Forming on a plaster mold. The above twelve-cavity plaster molds are used on a straight vacuum machine. They may be removed for changes by merely lifting them out of place. Halloween masks of .025 in. flexible vinyl sheet are being made. The four-color printing of one dozen different faces at a time is registered within the clamp frame and when formed it is accurately positioned. (*Courtesy Topstone Toy Co.*)

Some people reinforce the plaster with various plastic additives to strengthen the basic mold but generally the interior of the mold is reinforced with screening or metal (burlap as used by sculpturers is sometimes preferred). In some cases the molds are cooled by casting coils into them but there is considerable disagreement as to the effectiveness of this type of cooling.

If a plaster mold is mixed in the proper proportions and is properly cast (and this is a great technique to be learned) it can be ten times as strong as one which is poorly cast. The producers of this high-gysum cement offer excellent books which should be followed carefully.

Surface coatings such as the phenolic and the epoxy resins have been successfully used to provide a hard, durable wearing surface.

Production runs up to 300,000 pieces have been successful with plaster molds. Generally it is the mainstay of the display field, Christmas decoration field, parts of the toy field, and it is used by the government for military maps. One mold supplier lists the cost of such molds at $12 to $15 per square foot plus $2 per inch of elevation or depression.

## Plastic Molds

Plastic molds are in general an improvement over plaster molds due to their greater durability, longer life, better detail, and good dimensional stability. They are made of cast phenolic, cast furan, and cast epoxy. These materials cost more per pound than plaster and take longer to fabricate. Plastic molds require a curing period during which a combination room and moderate oven temperature is maintained to set them. Some furan and epoxy resins are available that cure at room temperature without the use of an oven, thus simplifying the process since the enormous size of some molds would require an extremely large oven. The cast plastic molds have proved satisfactory for medium production runs and runs of a half million pieces have been made successfully.

While some of these molds have had cooling lines cast in them to reduce the temperature, plastic molds in general tend to hold the heat thus presenting some problems where the material is critical. Some mold makers advocate the mixing of metal powders such as aluminum or iron to improve the heat transmission. Such molds are used in packaging, some lighting products, signs and displays, toys, industrial items, novelties, and some household items.

A good estimate of their cost would run from $40 to $50 per square foot plus $5 to $10 per inch of elevation or depression.

## Sprayed Metal Molds

For products requiring extremely fine detail such as grains, fabric replicas, and tooled leather designs, metal spraying has been found to be the most satisfactory. It is capable of producing long production runs—estimated at as many as a million pieces—and it is reasonably inexpensive. It has one disad-

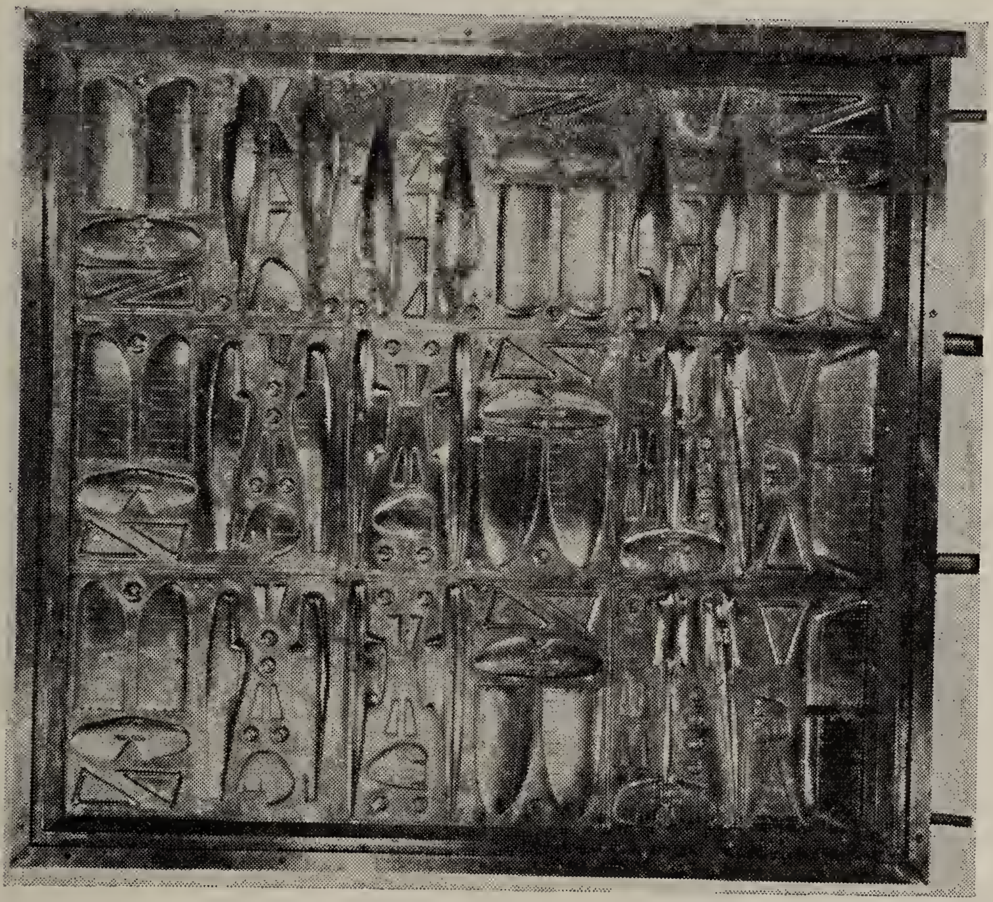


Figure 5–3. The metal-sprayed mold shown above was of a zinc base material backed with an epoxy resin. Vent holes were provided by inserting pins in the original pattern and spraying around them. Water cooling was sprayed in place against the basic metal prior to applying the epoxy vacuum. The airplane kits made with this mold are fabricated in one sheet; nine kits are formed at one time. (*Courtesy Metalmold Co.*)

vantage in that metal spraying is relatively soft and brittle and these molds cannot stand abuse without destroying the design.

Basically, metalizing or metal spraying is performed with a spray gun or nozzle which feeds the metal in wire form through an oxygen gas flame where it is atomized by a blast of compressed air. The molten metal emerges in fine metal particles exactly as from an ordinary paint sprayer and the operator sprays and builds up on the master exactly as if it were paint.

This type of mold is formed by spraying zinc and aluminum over a master mold made of fabric or some other material, including plastic, to a shell thickness up to 3/16 to 1/4 inch. Prior to spraying many fine pins are inserted into the master mold, sticking out a distance of 1/2 inch or more depending on the thickness of the final mold. If cooling is required, coils are placed in back of the shell and sprayed in place with added metal. In order to keep the cost at a minimum the back is then filled with a resin (such as epoxy) or with plaster. When the mold is finished the pins are removed, thus forming the vent holes necessary for sheet forming molds.

This type of mold has a long life and high detail surface. However, it is seldom used for deep molds, but is generally used for shallow molds such as are necessary to produce place mats, bath mats, fine displays, some packaging, automotive door panels with their fine leatherette detail, wallets and ring binders. Sprayed metal molds usually cost from $75 to $100 per square foot.

## Cast Aluminum Molds

At present, cast aluminum molds are the best for long production runs or for items requiring great dimensional stability or high quality. New techniques have enabled molds to be made by casting the aluminum against plaster instead of sand,

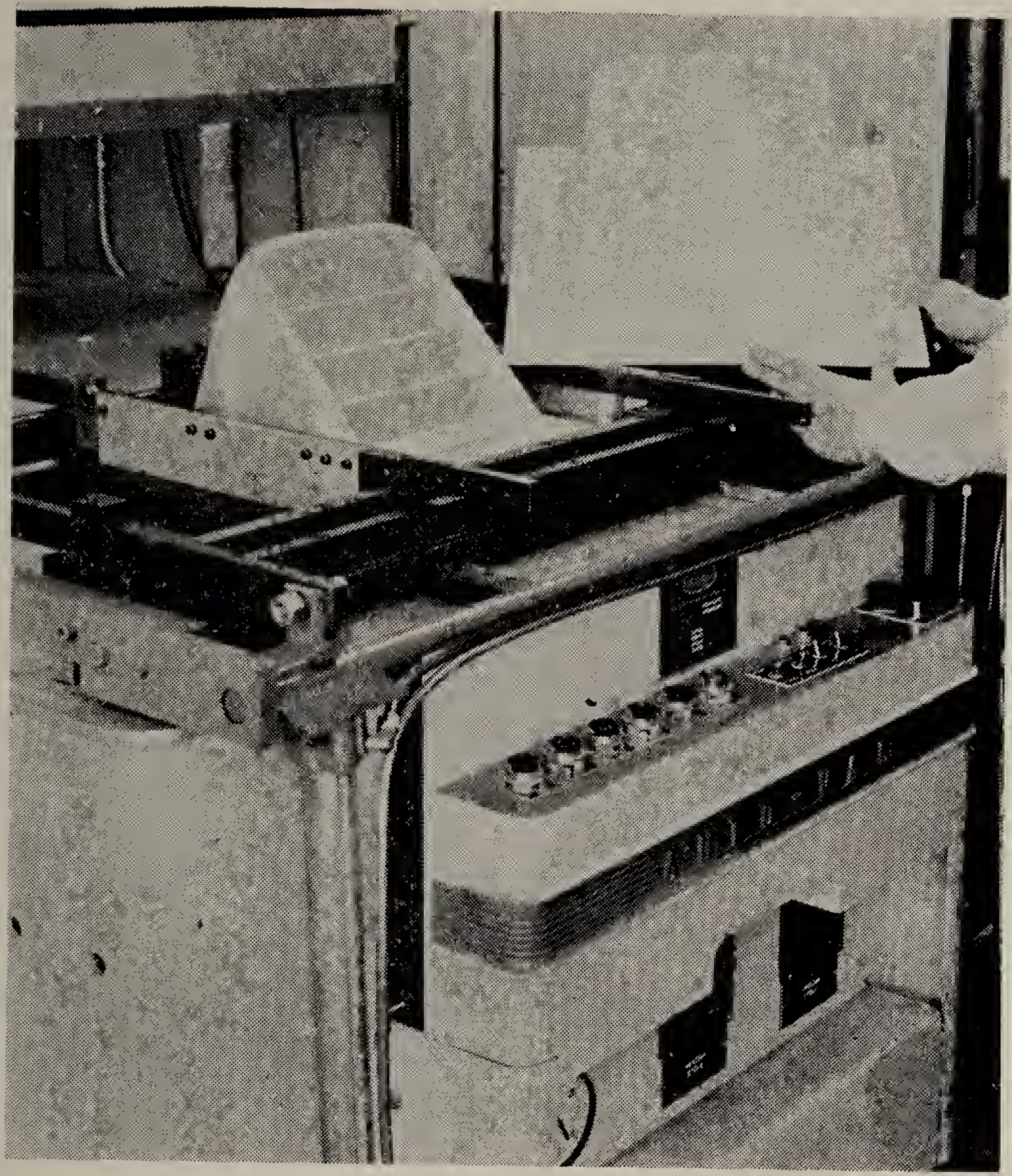


Figure 5–4. Forming on an aluminum cast mold. The deep drawn cigarette display shown above was formed on an aluminum casting mold with water cooling. The fine polishing resulted in an accurate part with no surface defects. The material used is .080 in. styrene copolymer.

thus requiring little finishing. The dimensional tolerance and the surface uniformity of the mold are such that it may be used with only light polishing, thus a designer can make his original wood pattern, allow for the aluminum and plastic shrinkage in the sheet-forming application, and arrive at a final part within the dimensional allowance of the product. In most all high production molds cooling coils are cast in place. These are generally stainless steel tubing approximately ⅜ inch in diameter. A good rule of thumb in a casting having a mean thickness of ⅜ inch is to place the tubing approximately 2½ inches apart throughout the mold. When used in combination with a temperature controlled unit which provides cold or hot water when required, these molds will maintain their proper temperature under the severest forming conditions.

Pattern costs are slightly less than those required for regular casting since only one side has to be constructed. A mold with cooling coils can generally be made for under $5 per pound; however, finishing, mounting, and drilling may cost another $5 per pound. A refrigerator door mold approximately 24 × 48 inches can be made for approximately the following:

| | |
|---|---|
| Pattern .......... | $1,000 |
| Casting .......... | 600 |
| Finishing and drilling ........ | 600 |

The life of these molds is indefinite since there is little wear, and they can be repaired easily. These molds are now standard for packaging, appliances, automotive, lighting, some displays, toys, industrial and household items.

## Electroform Molds

Electroform molds are generally used wherever sprayed metal molds are used. They are made by electroplating on a master immersed in a plating solution. They are considerably more durable since the electroformed deposits make a strong shell. However they are considerably more difficult to make since the master must be carefully prepared. Generally the pins cannot be placed in the master to form the vent holes and these must be drilled in after the shell is complete. Most of these molds are made of copper and electroformed to a thickness of ⅛ inch.

They are mainly used for flat detail molds such as automobile door panels, place mats, wallets, and bath mats. Deeper molds for displays have been made backed up with plaster or plastic. The cost of these molds must usually be determined from the product. It is estimated for flat work that they range from $100 to $175 per square foot. Some sheet formers use this type of mold to produce formed sheeting for the handbag and shoe trade.

## Machined Metal Molds

Some molds, especially those made for pressure forming, may be machined completely from brass, aluminum, or steel. Machining molds rather than casting which requires the use of patterns is economical if machining directly on modern machine shop tools. They are capable of producing high precision parts without any defects since they may be polished to a very high gloss.

This type of mold is becoming more and more popular as a result of the greater precision required for some sheet-formed parts. One appliance manufacturer uses this type of mold to form a washing machine lid. It was mounted on a separate

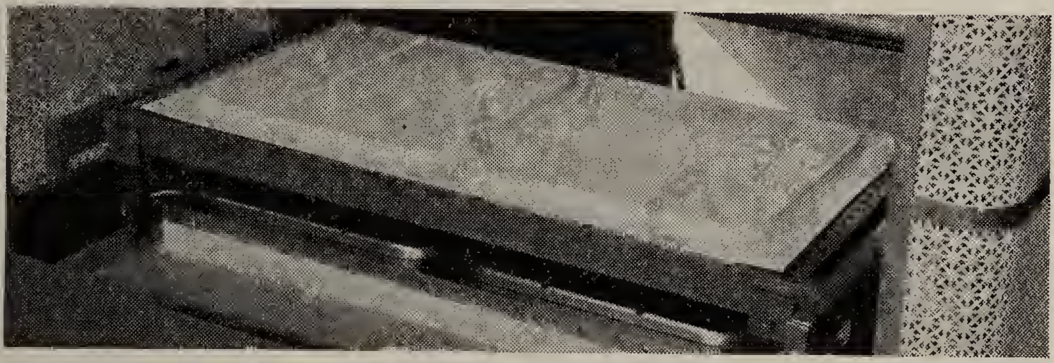


Figure 5–5. Forming on a machined-metal mold. The two-cavity mold shown above was machined from cold-rolled steel and then mounted on a steel plate which was cored for water. The part, a small washing machine cover, is made of .100 in. styrene copolymer in various colors. Production cycle was approximately 65 seconds.

plate with drilled cooling lines and exhibited a remarkable temperature uniformity. The cost of the mold is completely dependent on the product. However the material must be carefully considered since fine venting holes may have to be drilled.

## Mold Design

In addition to the sheet material and the method of forming, the design of the mold may be as important as the other two together. Certain basic fundamentals must be utilized for best results. In general, the following can be used as a basis for the general design:

## When to Use the Male Mold

1. To get the sharpness of a design on the inside of the part, since the side facing the mold will always be the sharpest.
2. To get stronger parts.
3. To keep mold costs to a minimum.
4. To reduce the number of defects.

A female mold is preferred when the design or embossed area is on the side toward the mold (generally considered the outside of the part); when the depth of draw is low relative to the size of the part, female molds may be placed close to each other since there is no stretching required between cavities; when the type of forming decided upon, such as plug forming, will permit the use of female molds.

In general, various other rules must be followed:

1. The mold must be properly vented so that the action of the plastic will be rapid, otherwise the plastic will cool during the forming operation. Deep corners, which would tend to entrap air, must be vented. Large flat areas require little or no venting. It is some times possible to get a very clear part without venting since there is no pressure forcing it against the

mold. The size of the vent holes should be as small as possible. For work involving pressure the holes should be in the order of .015 inch diameter. For thin guage vacuum forming it should be in the order of .015 to .025 inch; for heavier guage work it should be in the order of .020 to .035 inch. Larger holes will show up on the finished part. Male molds are generally set on shims .010 inch thick over the platen, and vacuum pulled underneath the entire mold for good formations.

2. Undercuts should be avoided unless the entire project is designed for them. In a female mold the plastic will shrink away from it facilitating removal of undercuts. In a male type mold the part will shrink deeper into the undercut making removal more difficult.

3. Right angles should be avoided if possible. On female molds this would be the extreme bottom corner and would be very weak due to the fact that it will thin out excessively; on male molds this would be the top corner and would prevent proper material flow over the corner and down the side walls.

4. Parts should have enough draft to permit the material to form correctly; a minimum of two to three degrees is considered acceptable. A larger draft would improve the part considerably.

5. Radii should be kept as large as the design of the article will permit. In no case should the radii be less than the stock thickness.

6. Wherever possible reinforcing ribs or designs should be incorporated into the weaker sections of the product. This will increase rigidity considerably, and is desirable in the case of large, flat surfaces.

7. Where a permanent insert is locked into the mold care should be taken to check the coefficient of expansion of the two materials when the product is in use or else severe cracking may occur. This type of insert, known as an orphan insert, is placed in the mold to form some projection or undercut and

remains a permanent part of the plastic product. Undercuts may also be formed by the use of a retractable type metal insert which is actuated after the part is formed to permit removal of the finished product. This is quite commonly used to form shelf brackets in refrigerator door liners.

8. Shrinkage. To obtain the proper dimensional tolerance of the final product the mold should be made oversized so that when the product is removed and cooled to room temperature it will have the correct dimensions. Shrinkage is figured in inches per inch and will range from .000 to .040 inch per inch. For example, styrene copolymer has a design shrinkage of approximately .0045 inch per inch; low pressure polyethylene has a design shrinkage of from .020 to .040. It is important to check with your material supplier for the correct dimensional shrinkage before proceeding with the mold construction. Any change of formulation may affect the final shrinkage.

In general, many of the vacuum forming products do not require very close tolerances so that materials may be interchanged to produce acceptable parts without dimensional change of the mold.

Proper attention to the mold and mold design will result in a large saving in production costs. Most sheet formers make their own molds in order that they can closely control this phase of the fabricating.

# 6. COMMERCIAL MACHINERY

Much of the credit for the great spurt in sheet-forming can be given to the development of commercial machinery. While many of the methods were known for several years, actual production was limited due to the difficulties of designing and producing a variety of sheet-formed products. Early machines were generally built for one specific production run and had to be rebuilt for each new product.

The basic machines now available must have certain specific features for high production and good quality parts. Since the machines vary from manufacturer to manufacturer, these components may differ widely, but their result must be the same. All machines have the following:

1. A heater to bring the plastic sheet to its formable temperature.
2. A clamp frame to hold the material while it is heating, forming, and cooling.
3. A mold base or platen for holding the mold or molds.
4. A vacuum or air-pressure source for pulling or pushing the heated plastic sheet into or over the mold.
5. Various mechanical devices to move the clamping frame, heater, molds, plugs, etc., in relation to each other to form the plastic sheet in the various processes.

From the above it can readily be seen that a sheet-forming machine can be very simple and that it can also be very complicated. Completely automatic machines are necessary when maximum production per man hour is desired. They provide a precise heating time and minimum cooling and operating times, and are usually equipped with manual push buttons for set up and mold change.

## Size

Since sheet forming can produce parts of considerable size, the selection of a machine depends on the dimensions of the part to be produced. Sheet forming machines are available with a forming area as small as 6 × 6 inches, and they vary in size up to 72 × 150 inches, which is the largest constructed to date.

The depth of the parts is also important. Parts up to 36 inches deep have been formed. However the average parts are under 12 inches deep, and about 95 per cent are under 24 inches.

Thus, in selecting a machine one must first consider the maximum forming area. Most machines will adjust down from this maximum size to smaller divisions for smaller parts. Manufacturers may also have a minimum size since some parts may be too small to fit satisfactorily on a large machine, i.e., a machine with a 10 square foot forming area may have a minimum forming area of 1 square foot.

The general classification of sheet forming machines is as follows:

| Sheet Forming Area | Some General Commercial Sizes |
|---|---|
| 3 sq ft or less | 12 × 12 — 16 × 16 — 18 × 18 |
| 3 to 6 sq ft | 20 × 25 — 20 × 30 — 24 × 24 — 24 × 36 |
| 6 to 12 sq ft | 30 × 30 — 30 × 50 — 36 × 36 |
| 12 to 18 sq ft | 42 × 42 — 50 × 50 — 42 × 60 |
| 18 to 30 sq ft | 42 × 72 — 48 × 72 — 48 × 96 — 60 × 60 |
| Over 30 sq ft | 60 × 90 — 72 × 150 |

Since sheet-forming machines are frequently made to order there are many variations in their capacities. A general rule of thumb is that front-to-back forming dimensions vary by 6″

starting at 24″ such as 24″, 30″, 36″, 42″, 48″, 60″ and 72″. Left-to-right forming dimensions vary by 12″ starting at 24″ such as 24″, 36″, 50″, 60″, 72″, 84″ and 96″. The 50″ dimension, instead of 48″, is a concession to the 50″ to 54″ sheeting which was generally available when sheet-forming machines were first constructed.

The maximum depth of draw varies from machine to machine and in general the smaller machines have less depth of draw. The general available depths are: 6″, 8″, 12″, 15″, 18″ and 24″.

Another important consideration in the selection of machinery is the maximum and minimum thickness of the plastic sheet which can be formed. Some equipment can handle sheet from .003 to 3⁄16 inch thick with automatic compensating clamps. Adequate pressure is required for all of the various plastic materials. The heater is important in this case since an improperly compensated heater will not uniformly heat thin gauges. A machine with two side heaters may be necessary for heavy guages (up to .250 inch thick). In general, the average single side machine will perform satisfactorily on most materials from .005 to .125 inch thick, and on certain materials from .003 to .187 inch. The two-sided heater will usually operate satisfactorily on .0075 to .250 inch thick plastic sheets.

## Vacuum

The use of vacuum as a forming agent for the heat softened plastic sheet accounts for a majority of the commercial machines in use today. Vacuum molds are easy to construct and easy to mount since the vacuum tends to lock the mold to the platen. However, since the pressures are low the valving and piping are large, ranging from 1 to 6 inch in diameter.

The vacuum system consists of a vacuum pump and reservoir or single tank. The vacuum pumps are of the high-capacity rather than the high-vacuum type and deliver vacuum approximately 28 inches of mercury or 14 psi. Both the piston and rotary types are used with success and have capacities from approximately 2 to 150 cubic feet per minute. Some pumps require water cooling, however, most of them are air-cooled units. Vacuum surge tanks are quite large, containing up to 600 gallons. The selection of the pump, tank and vacuum valve is closely calibrated in a machine so that the recovery rate is sufficient to keep the vacuum level between 24 to 28 inches of mercury (12 to 14 psi) throughout the production run. It is important to realize that altitude has a great effect on the vacuum pressure, i.e., a vacuum-forming machine in Mexico City only delivers about 18 inches of mercury 9 psi. Most machines have the surge tank built in; however, for multiple machine operation a central vacuum system is installed and vacuum piped to the individual machines. This saves space and reduces the cost of the individual machines.

## Heating

Of all the requirements for good sheet forming the heating cycle is by far the most important. Without fast uniform heating no part can be economically produced. After trying steam, hot water, hot oil and gas heat, all machinery today uses electricity for heating.

A radiant type heat using electric resistance wire in some form is employed. Heater temperatures are variable and the selection of the proper temperature depends on the material, mold, and type of product. Once set the temperature is never changed but the time of heating the sheet plastic may be varied. The temperatures used generally range from 650 to 1500° F. The consumption of electricity is high, ranging from 1 to 3 kw per square foot so that a machine with a 10 square foot forming area would require from 10 to 30 kw. Most machines however have controls which keep the heater at an even temperature and which turn it off when it is too hot and on when it is too cold with plus or minus 5° F so that actual use of electricity would be approximately the capacity—thus a 30 kw heater would use about 15 kw hours.

Until about three years ago many machines used heaters made with "Nichrome" resistance wire encased in glass fiber tubing and cloth. This produces a flat mat heater of uniform temperature, however it cannot exceed 800° F since the glass will crystalize at higher temperatures. As the machines improved these proved too slow and heaters operating up to 1500° F were developed. These instantly improved the production cycle by reducing the heating time by more than one half. For instance, styrene copolymer .080 inch thick would require approximately 80 seconds with a glass fiber heater, whereas with a radiant type high-temperature heater at approximately 1400° F it would require from 25 to 30 seconds.

Most of the new machines have heaters with the enclosed tubular type elements of stainless steel, and have a good life at temperatures up to 1500° F. These elements are completely sealed in the metallic cover and are protected from humidity, dust, mechanical abrasion and fumes from the plastic being heated. This sheath also makes the heater completely safe since the electric circuit is inside and completely insulated from the external sheath. The heating rods are arranged in a pattern to compensate for heat loss at the edges and for heater travel from the rear toward the front, and return, so that the heater spends a greater length of time over the rear of the sheet. Reflectors over the heating rods direct the heat downward and spread it over the plastic in a predetermined pattern. The heaters are made of stainless steel for corrosion resistance and are heavily insulated to give uniform heat, to save electricity, and to prevent excess heat loss. An insulation box is provided in the rear or non-heating position of the heater to prevent heat

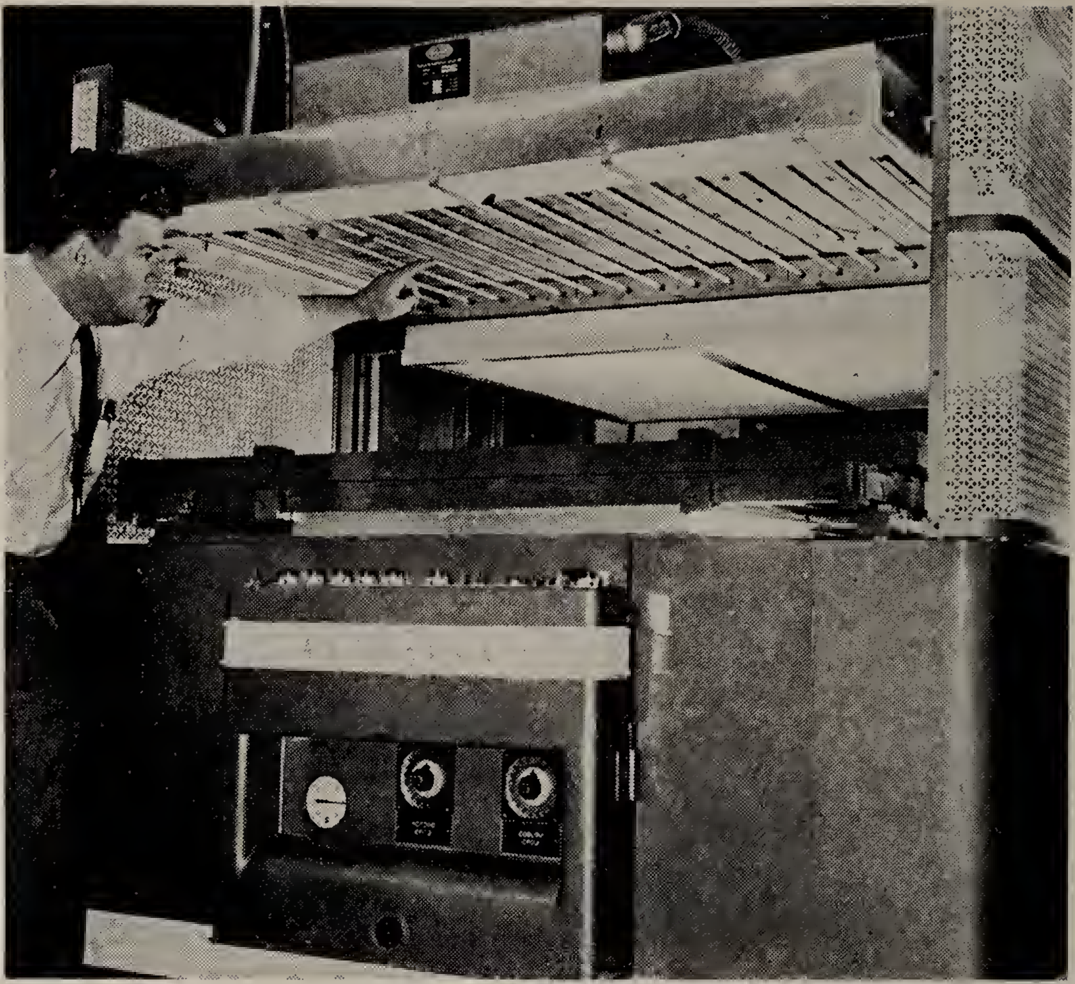


Figure 6–1. High-temperature heater.

loss to the working area and to keep the electrical consumption at a minimum. In some of the larger machines sections of the heater may be turned off when smaller sheets are used, thus saving electricity and also keeping the operating area cooler.

The design of these machines is such that the heater can attain proper operating temperature in from 5 to 7 minutes. Thus the machines are ready for operation quickly and may be turned off when molds are changed or delays encountered.

Most modern machines are either completely automatic or semi-automatic. In addition, push buttons are available so that the set-up and the various time cycles for the specific forming can be tested manually. After the process has been smoothed out, the machines are switched to automatic control and production may be started.

Compressed air has been selected for controlling the movements of the machines, since the long strokes and variable speeds required can best be handled by this means. Electric solenoids activated by electric timers control the movement of the compressed air. For example, if the heater is maintained at a set temperature of 1400° F the time of heating is determined by moving the heater over the plastic sheet by a micro second timer. If the sheet were .080 inch styrene copolymer it would have reached its forming temperature of 325° F in approximately 25 to 35 seconds. Of course, the heater is moved with great speed (as much as 22 inches/sec.) to provide uniform heating.

The machines are usually constructed of heavy steel to take the shock of the moving parts. Although most sheet forming machines have large forming areas and although only 14 psi are used, the resulting total pressure may be high. That is, on a machine of 30 square foot forming area the total pressure exerted by the vacuum would be over 60,000 pounds. As a result of this high pressure, steel construction is employed in the table or platen area.

## Types of Commercial Machinery

### LABORATORY OR PILOT-RUN DESIGN

MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

The laboratory or pilot-run machine is designed to provide a low-cost machine for companies desiring to familiarize themselves with the sheet-forming process, for companies with large equipment to enable them to test molds and product designs without interfering with the production on other equipment, and for companies with short-run production. It is also used extensively for sampling, such as skin packaging, and to provide market testing samples.

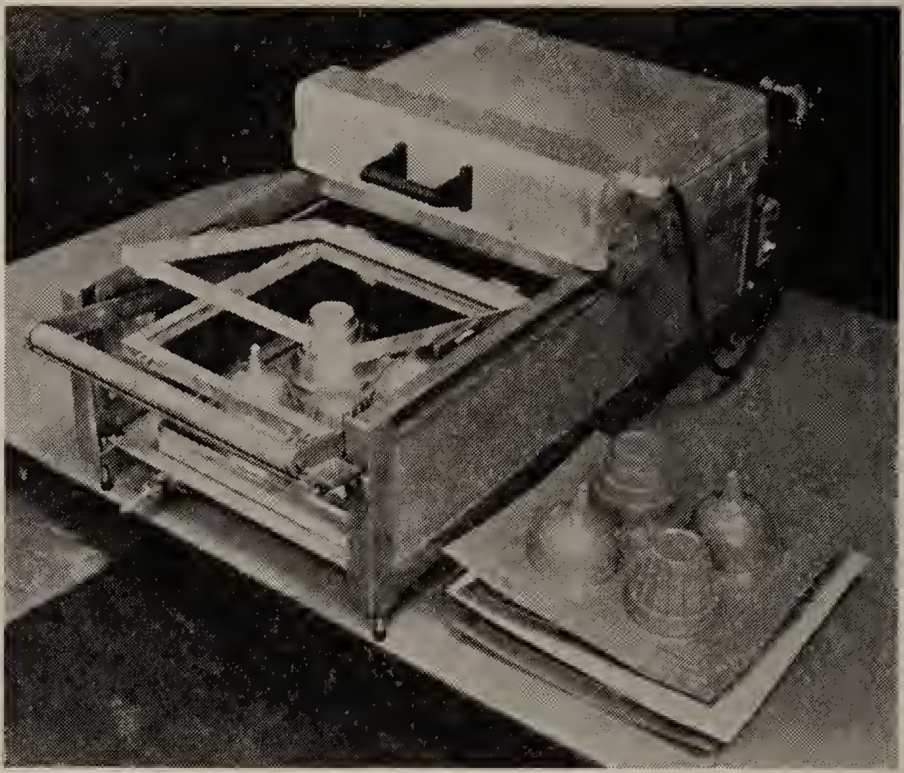


Figure 6–2

It is a completely manual machine, in keeping with its low cost, and it will form parts up to 16 × 16 inches and up to 6 inches deep. It will form parts either by the straight vacuum process or by the drape process.

The heater is of the high-temperature type using stainless steel heating rods and stainless steel construction. It operates on a free running basis using no heater temperature control but it will maintain a temperature between 1100 to 1400° F on an input voltage of from 205 to 230 volts. It occupies an area of 2 by 4 feet and has its own vacuum pump and tank built in the frame of the machine.

In operation the hinged clamp frame is opened and the plastic sheet placed on the lower frame. The top frame is closed and locked by two spring clips. The mold has previously been mounted on the platen over the vacuum part. The heater is brought forward manually on the two sides of the machine which serve as rails, and when the plastic sheet has reached its proper temperature, which may be determined visually or by the timer clock mounted on the machine, the operator grasps the handle, releases the clamp frame and pulls it down over the mold. At the bottom of this stroke the plastic sheet is sealed over the edges of the mold plate by pushing downward. On thin material the weight of the clamp frame is enough. The operator now trips the vacuum lever pulling the sheet to the mold. The heater must be pushed back manually and the part left to cool when the process is reversed to remove the part.

Simple conversion principles allow small frames to be inserted or drape assist frames added. Steps on the front of the machine provide stops for the draping so that parts from 0 to 6 inches may be formed.

With thin guage plastic sheet it is possible to form 1½ to 2 parts per minute; however 50 to 60 parts per hour is considered good production. The equipment is self-contained and needs only to be plugged in a 220 volt outlet.

It can handle most formable plastic sheets ranging from .003 to .125 inch thick.

### VACUUM FORMING AND SKIN PACKAGING MACHINE
### MANUFACTURER: COMET INDUSTRIES, FRANKLIN PARK, ILL.

A new improved model, the "Meteor" is a combination vacuum and drape forming machine. It forms all thermoplastics from .001 to .250 inch, and can be used for production, test work, models, short runs, and laboratory work.

Many of the new and improved features incorporated in the "Meteor" include form-drape-draw to 15 inches; automatic heating cycle; heating capacity adjustable through percentage input controller; rapidly adjusted clamp-frame; newly designed clamp-frame which eliminates plastic pull-out on all thicknesses; infrared rod-type heaters.

Standard equipment includes: oven with percentage input controller; timer 0 to 120 seconds with adjustable reset; clamp-frame kit; 15 inch drape mechanism delivers 720 pounds of force; air regulator; filter and oiler; 9-cfm vacuum pump with tank and contractor.

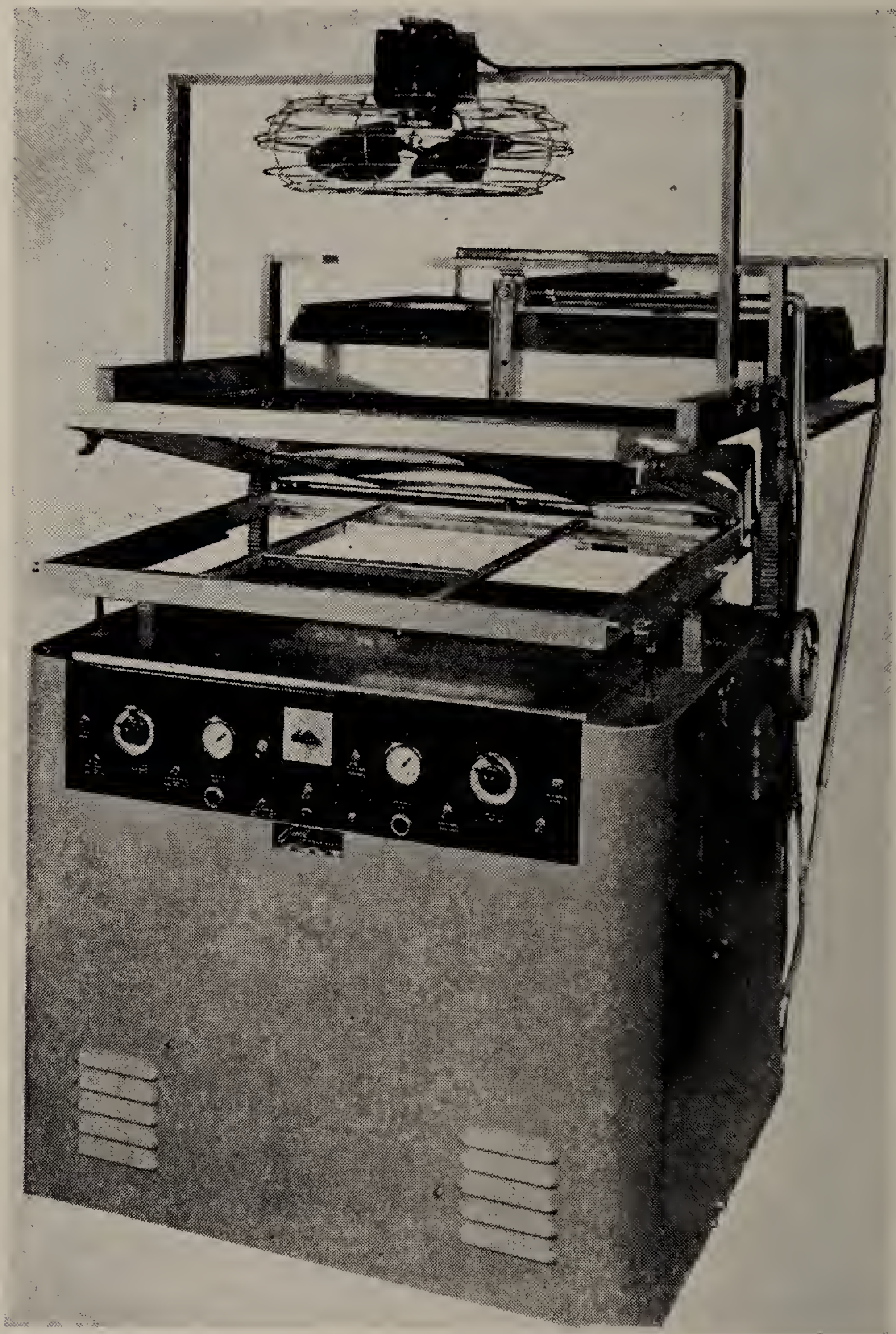


Figure 6–3

This model is made in three standard sizes: 20″ × 30″, 30″ × 36″, 36″ × 60″. Other sizes are available or can be custom-built to requirements.

### SINGLE STATION COMBINATION DRAPE-STRAIGHT VACUUM DESIGN

MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

The general-purpose machine shown here will form parts either by the straight vacuum or the drape process. It is available in several sizes, but the 24″ × 36″, 30″ × 50″, 42″ × 72″ and 48″ × 72″ sizes are the most popular. Drape strokes of 12 and 15 inches are in greatest demand.

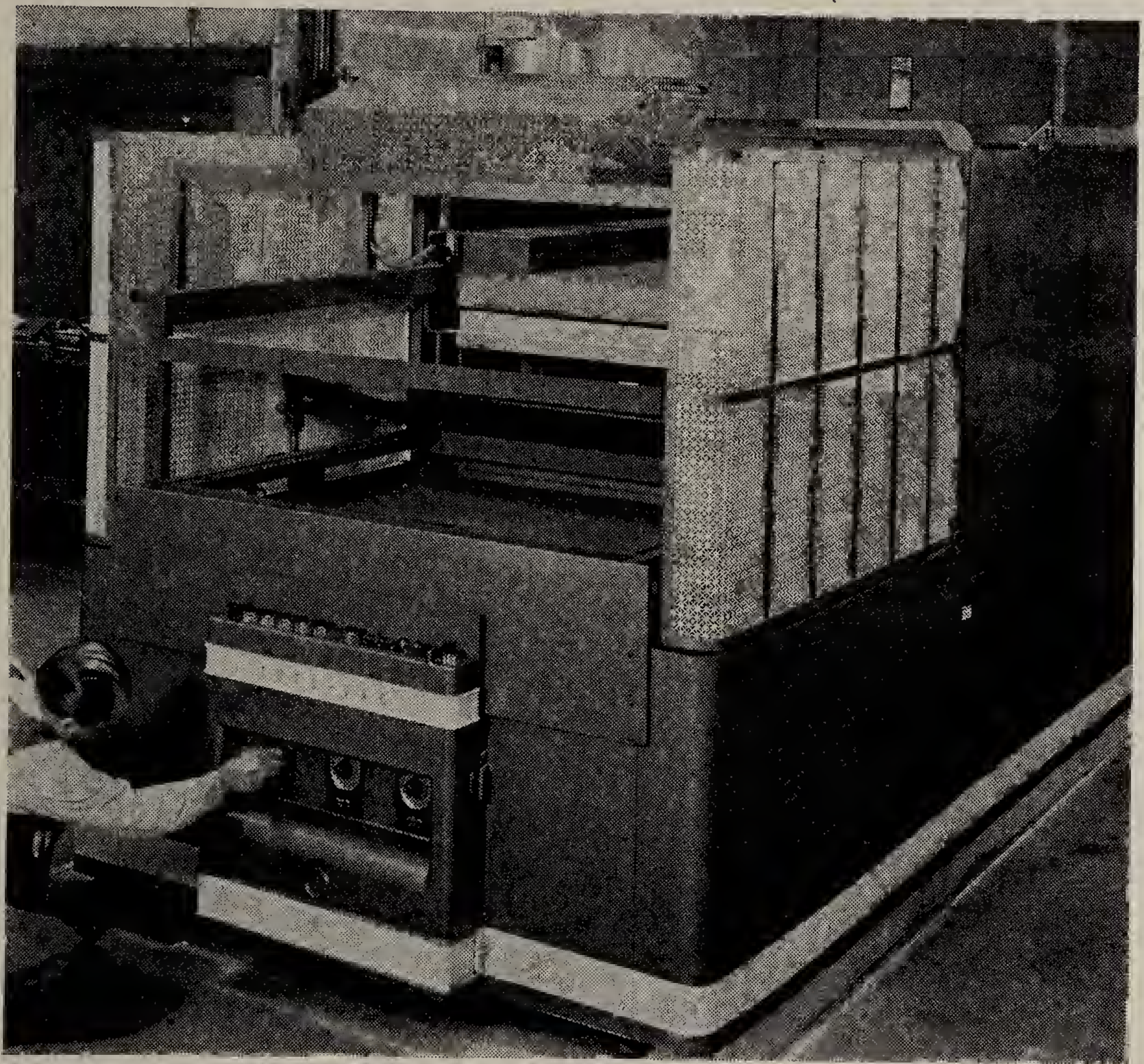


Figure 6–4

Operation is of the automatic type with manual loading and unloading. It can handle plastic sheets from .003 to 3⁄16 inch thick, and is extensively used in all branches of the sheet forming industry from refrigerator door liners to small packaging parts.

It has such features as timed heating, cooling and air blow-off cycles. The temperature range of the high temperature tubular type heater is from 100 to 1500° F with an accurate ±5° F temperature controller.

The clamp frame is completely adjustable for various sizes of plastic sheet and is self-compensating for various sheet thicknesses. The unit shown here has an overhead fan cooling unit controlled by the cooling cycle. A two-button safety starter is on all models, as well as side and front safety guards. It comes complete with vacuum system and electric controls, and circuit breakers. Rear roll feed for roll stock is optional equipment.

### 3-STATION ROTARY COMBINATION VACUUM MACHINE

### MANUFACTURER: COMET INDUSTRIES, FRANKLIN PARK, ILL.

This machine works on a 3-stage principle. The operator remains at one station where a finished form is unloaded and the clamp-frame reloaded with a plastic sheet. During this operation, a sheet is being heated at the second stage, and a heated sheet is being vacuum formed at the third stage.

The heating and forming operations are automatic. After loading the clamp-frame, the operator must place his hands on two safety switches to close it. The carriage for the clamp-frame then automatically moves to the heating stage, the heated sheet to the forming stage, and a finished product to the operator.

The oven at the heating station is completely enclosed. Two banks of Thermatron heaters sandwich the plastic sheet assuring quick and even heating. The upper and lower banks of heaters are each controlled from independent percentage input timers. Either bank may be cut out when working with extremely light gauge materials.

The watts per square foot for the upper bank are 1500; for the lower bank, 1100.

Vacuum molds are attached to the molding platen which has a 17 inch stroke. Two vacuum ports make forming on two molds possible at the same time.

The "Rotary-Vac," illustrated, is 15½ feet in diameter and has a 48 × 72 inch molding area.

An upper platen in the construction of the "Rotary-Vac" facilitates the use of male helpers, pressure and mechanical forming operations when required. Vacuum or air pressure may be used with the upper platen when additional forces are required. Extra terminals and an electric interlock are provided for molds with power actuated movable parts due to undercuts.

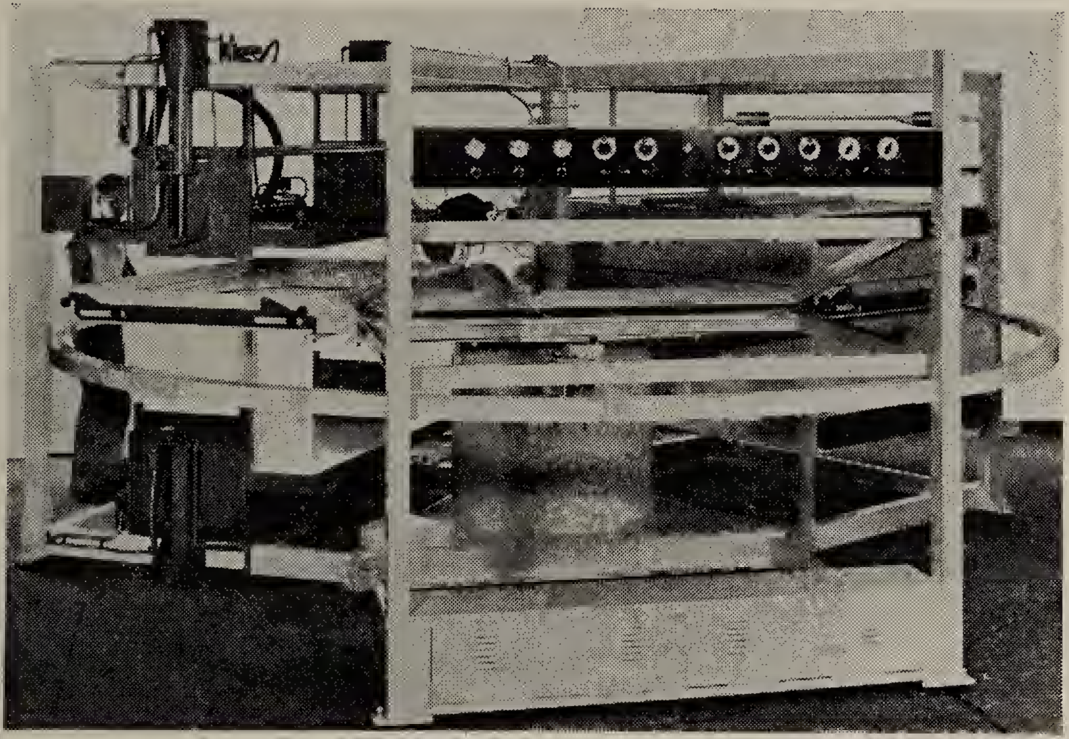


Figure 6–5

SINGLE-STATION COMBINATION DRAPE, STRAIGHT VACUUM AND PLUG MACHINE
MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

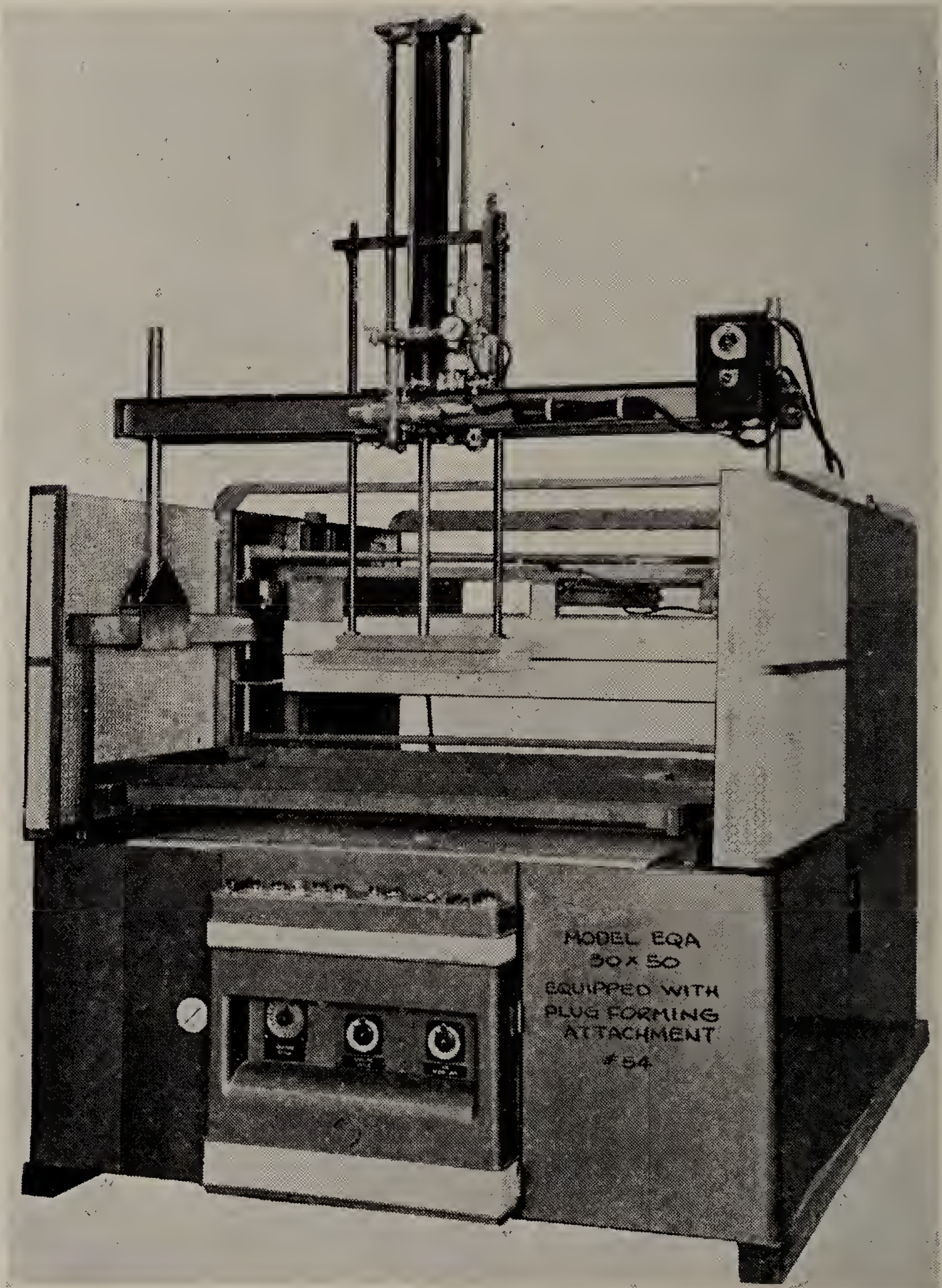


Figure 6–6

For general-purpose work the combination type forming press equipped with a plug attachment can perform most any job. Designed to provide equipment which will be multi-purposed, this machine comes in sizes from 24″ × 36″ to 48″ × 72″.

The plug action of 36 inches can form parts as deep as 18 inches. High-speed plugging action, as high as 24 inches per second, insures good drawing of difficult materials. A high-temperature type heater operates up to 1500° F for fast cycling. Heater control on plugging can be adjusted to the proper dwell for various types of materials. Operation is completely automatic on all phases.

It can operate automatically as a straight vacuum machine, as a straight drape machine, as a combination straight plug and vacuum machine, and as a combination drape and plug machine. These changes in operation are all incorporated in a simple switch mechanism so that the type of operation can easily be selected. The length and height of the plug stroke may be adjusted, as well as the initial and final speed of plugging.

It can handle plastic sheets from .0075 to $\frac{3}{16}$ inch thick. Overhead fan cooling is provided as extra equipment.

### SINGLE-STATION COMBINATION VACUUM PLUG MACHINE

MANUFACTURER: COMET INDUSTRIES, FRANKLIN PARK, ILL.

Known as the "Star," this machine with counteracting platens features snap-back mechanical forming, pressure forming, and light trimming.

The "Star" forming press was designed primarily for items hard to fabricate due to their shape or the thickness of the material. The counteracting platens provide for plug assist or hold back directing control on the plastic sheet during forming operations. Each platen is capable of carrying a mold or helper and performs a complete fabricating operation.

Vacuum may be applied through either or both platens simultaneously, depending on the forming technique desired. Even the simplest applications can make use of the sag in the sheet.

The basic operation consists of the automatic withdrawal of a superheated plastic sheet from an enclosed oven. The heating of the plastic sheet evenly on two sides reduces the cycle time to an absolute minimum. The oven may be gas, electric or oil heated.

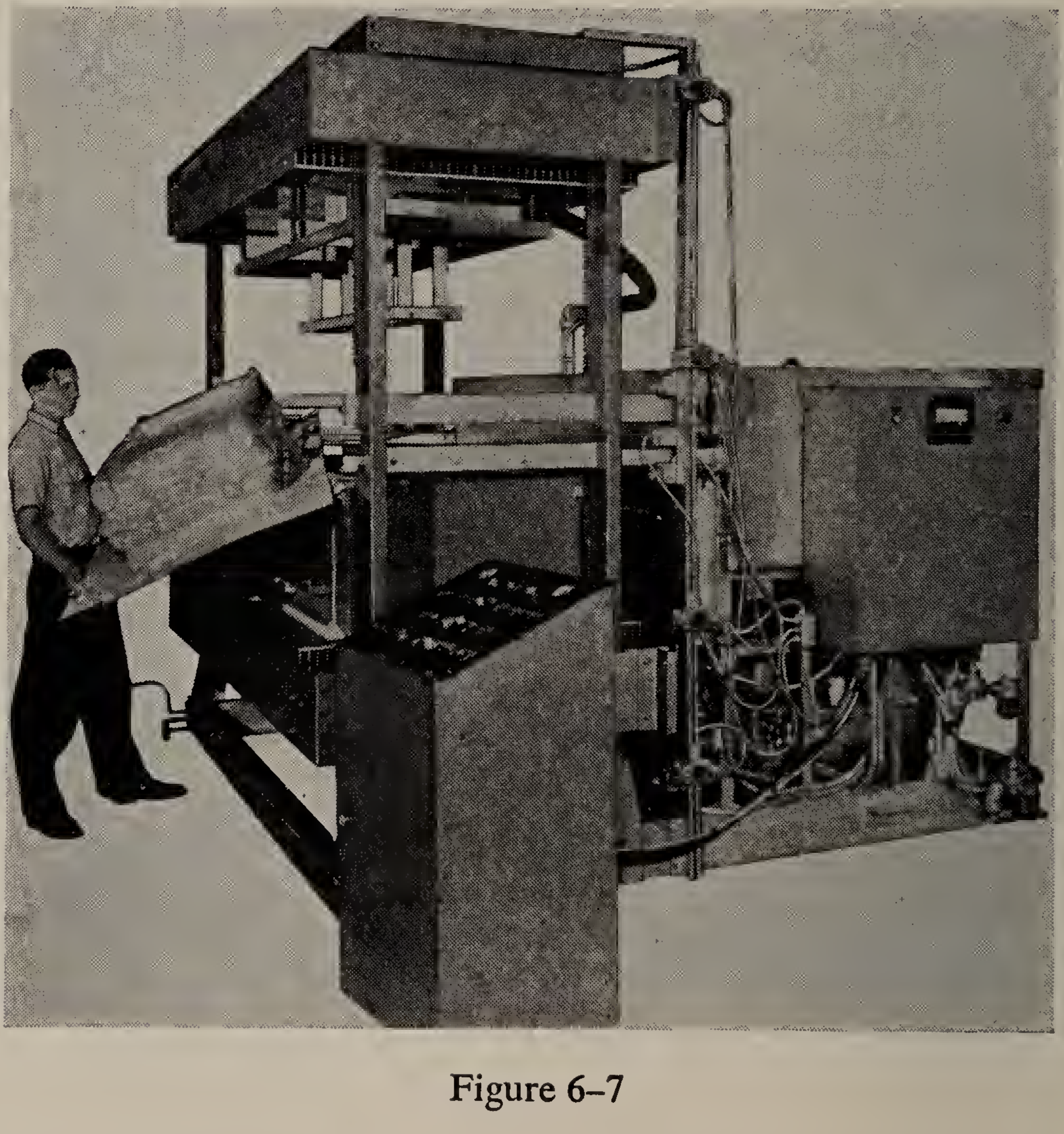


Figure 6–7

The sheet is securely clamped in a central position between the two platens. Each platen is electrically driven and individually controlled to and from the forming area.

Unlimited applications and combinations of forming techniques can now be accomplished automatically on this machine. Automatic cycling operations are preset on special timers. Loading and unloading operations may be by manual means, from extruder, or blanks automatically fed and automatically removed after forming.

The "Star" is available in four standard sizes from 36″ × 48″ to 60″ × 96″, with either single or double forming press. It can also be furnished fully automatic for continuous forming direct from extruder or individual sheet. Special sizes and strokes are available.

### ROLL FEED COMBINATION DRAPE AND VACUUM FORMING MACHINE.

MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

Designed for large area parts or for multiple mold set-ups, this machine will handle rolls up to 44 inches wide and can form parts as large as 42 × 72 inches.

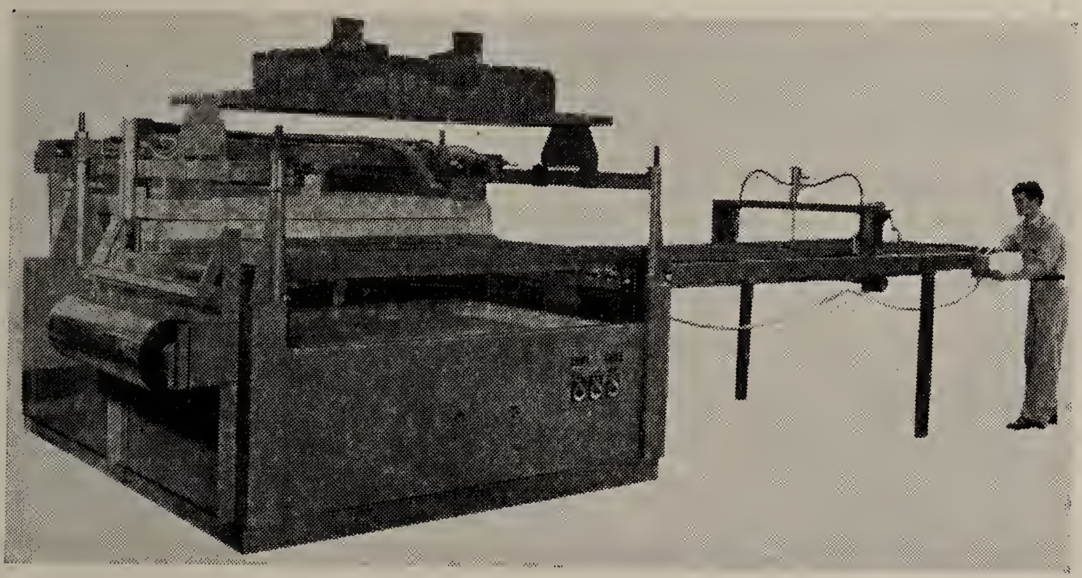


Figure 6–8

Designed especially for large blisters, box tops, wall and decorative panels, lighting fixture trays, box inserts, display trays, signs, toys, and housewares on a roll-feed set-up. For heavy guage applications this machine may be sheet fed to produce such items as refrigerator door liners, displays and signs, machine housings, and automotive aircraft parts.

Featuring high-speed operation of all machined components, it is completely automatic within itself, however the take-off is manually operated.

The operator runs this machine by remote control while feeding and cutting stock. Adjustable clamp frames, double fan cooling, and completely timed operations make it a fast production unit.

Especially designed for very thin guages, large areas of plastic material as thin as .003 inch thick may be clamped and formed without difficulty. Both male and female molds can be used.

### AUTOMATIC ROLL FEED COMBINATION DRAPE AND VACUUM FORMING MACHINE.

MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

Operating continuously without an operator, this machine handles roll stock 22 inches wide and up to .040 inch thick. Capable of operating four complete cycles per minute, it automatically feeds the stock, clamps it, heat forms and strips the mold from the plastic.

Automatic indexing moves the completed part to the next position and a new cycle commences. A synchronized shear cuts off the completed section.

It can be adjusted for various widths and various lengths up to a maximum of 20 to 30 inches.

Especially valuable for the production and packaging components, it will handle styrene copolymer, acetate, butyrate,

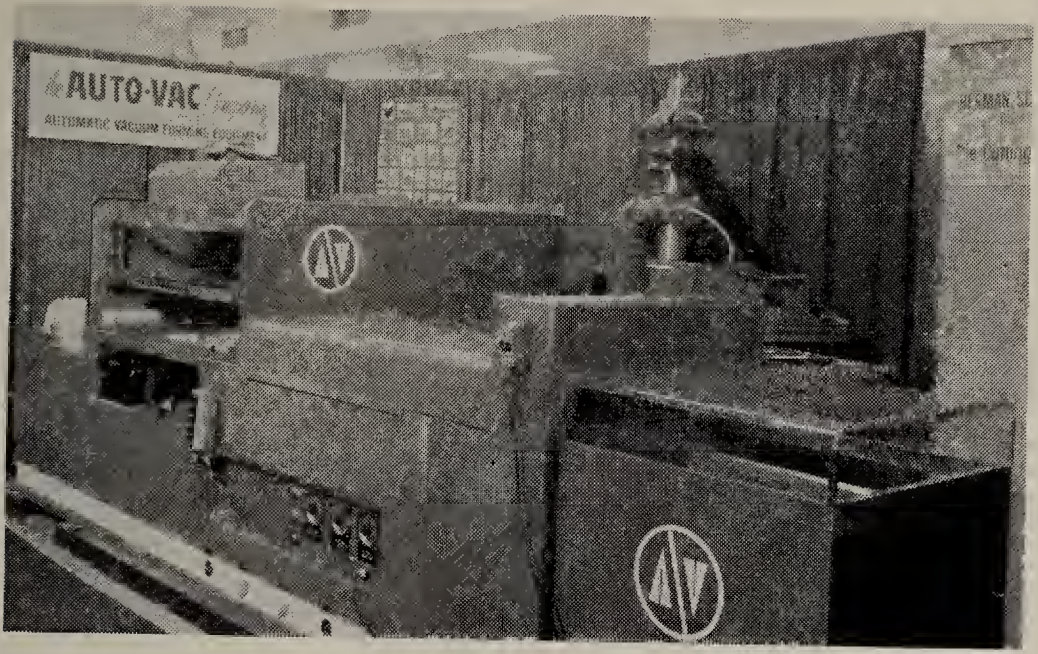


Figure 6–9

vinyl, and polyethylene. Overhead fans cut the cooling cycle to a minimum.

Complete with high temperature heater and both automatic and manual controls. Remote control starting and stopping allows it to be connected to and controlled by accessory cutting equipment.

Special modification convert this machine to automatic skin packing operations.

### COMBINATION SKIN PACK AND DRAPE FORMING VACUUM MACHINE.

MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

For fast roll feed applications such as skin pack or for the manufacture of packaging components, the "Auto-Pac" features minimum conversion to various types of forming by an electric selector switch.

For skin pack operations the automatic table transfers the work into the machine and at the proper time raises it to the forming area. A special skin packing control system insures

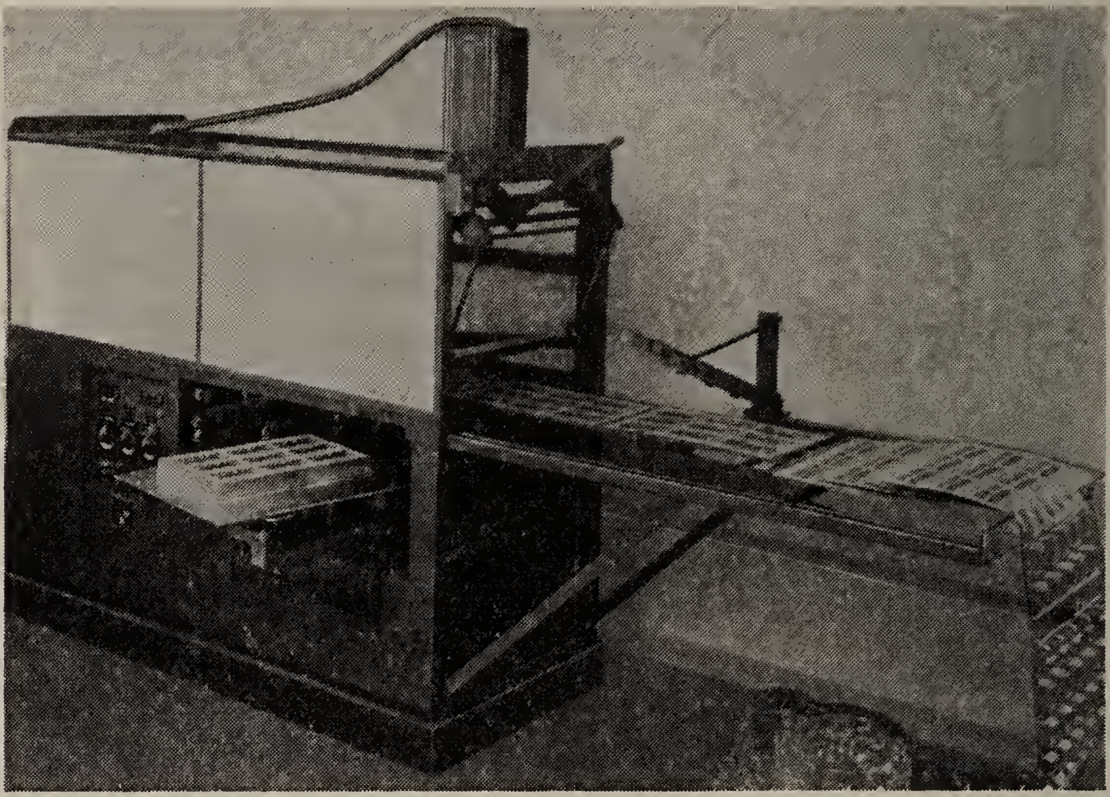


Figure 6–10

proper vacuum and heat for complete plastic to board adherence. A high temperature heater permits rapid cycling. A take-off table feeds the correct amount of plastic and has shears for cutting off complete formations or for cutting off multiple skin packed merchandise.

The machine will handle up to a 22 inch wide roll of plastic material. It has a maximum forming area of 20 × 25 inches; the maximum depth of product is 5 inches. Fan cooling is optional equipment.

CONTINUOUS PROCESS VACUUM FORMING AND PACKAGING MACHINE.
MANUFACTURER: COMET INDUSTRIES, FRANKLIN PARK, ILL.

This machine makes a complete bubble or contour package of clear plastic in a continuous process. It automatically inserts the product, laminates, heat seals, prints, trims individual

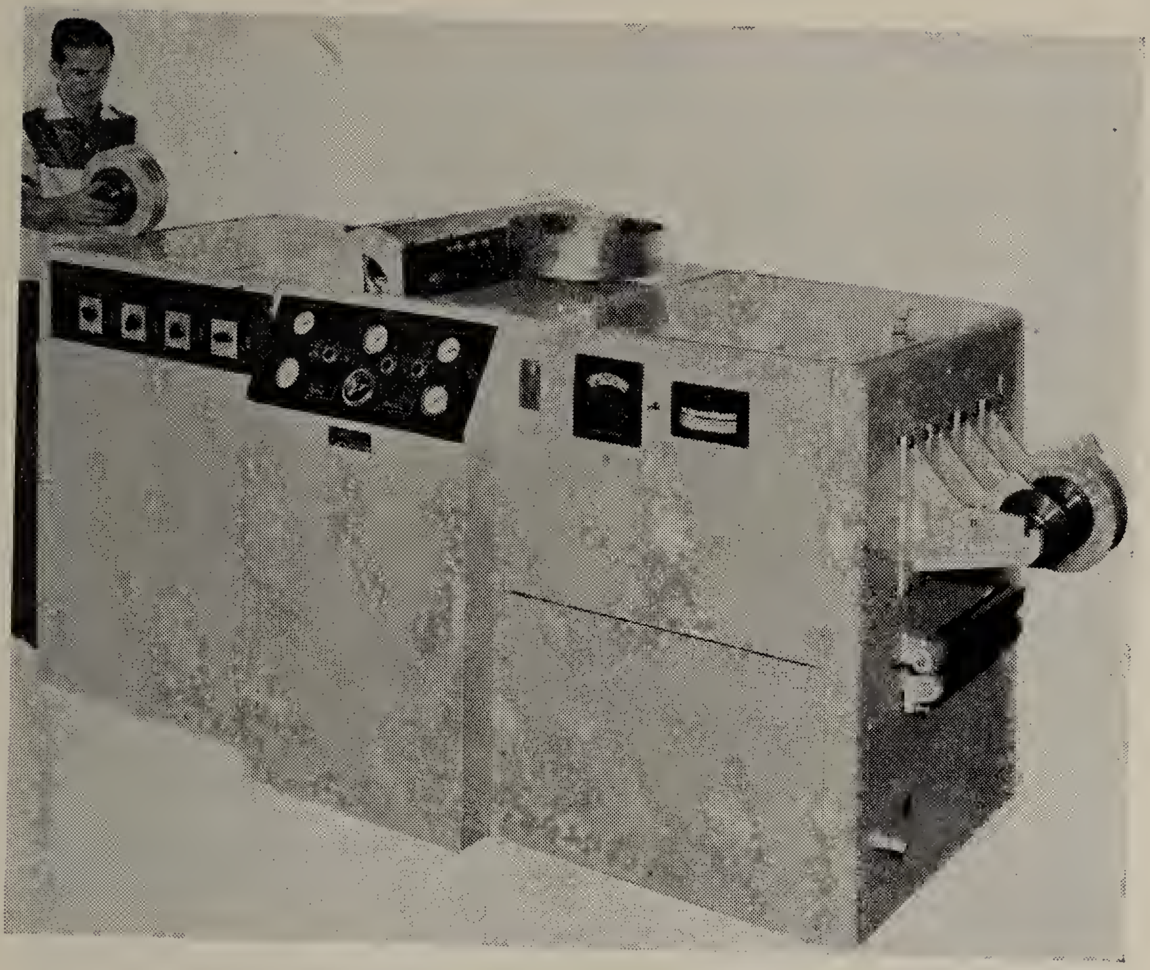


Figure 6–11

packages or rewinds the packaged product in a continuous ribbon.

It was basically designed for "Rol-Pak" and for other continuous vacuum forming processes on small parts, bubbles and containers. It has a high-speed fabrication—5 to 20 feet of plastic film per minute.

The "Rol-Pak" has several advantages: There is a savings in storage space—individually packaged items are kept together in a large roll and there is no loose stock. Each package is perforated for easy removal from the display or service roll. Inventory is easily taken from roll without counting individual pieces. There is no soiling of product or package (moisture proof).

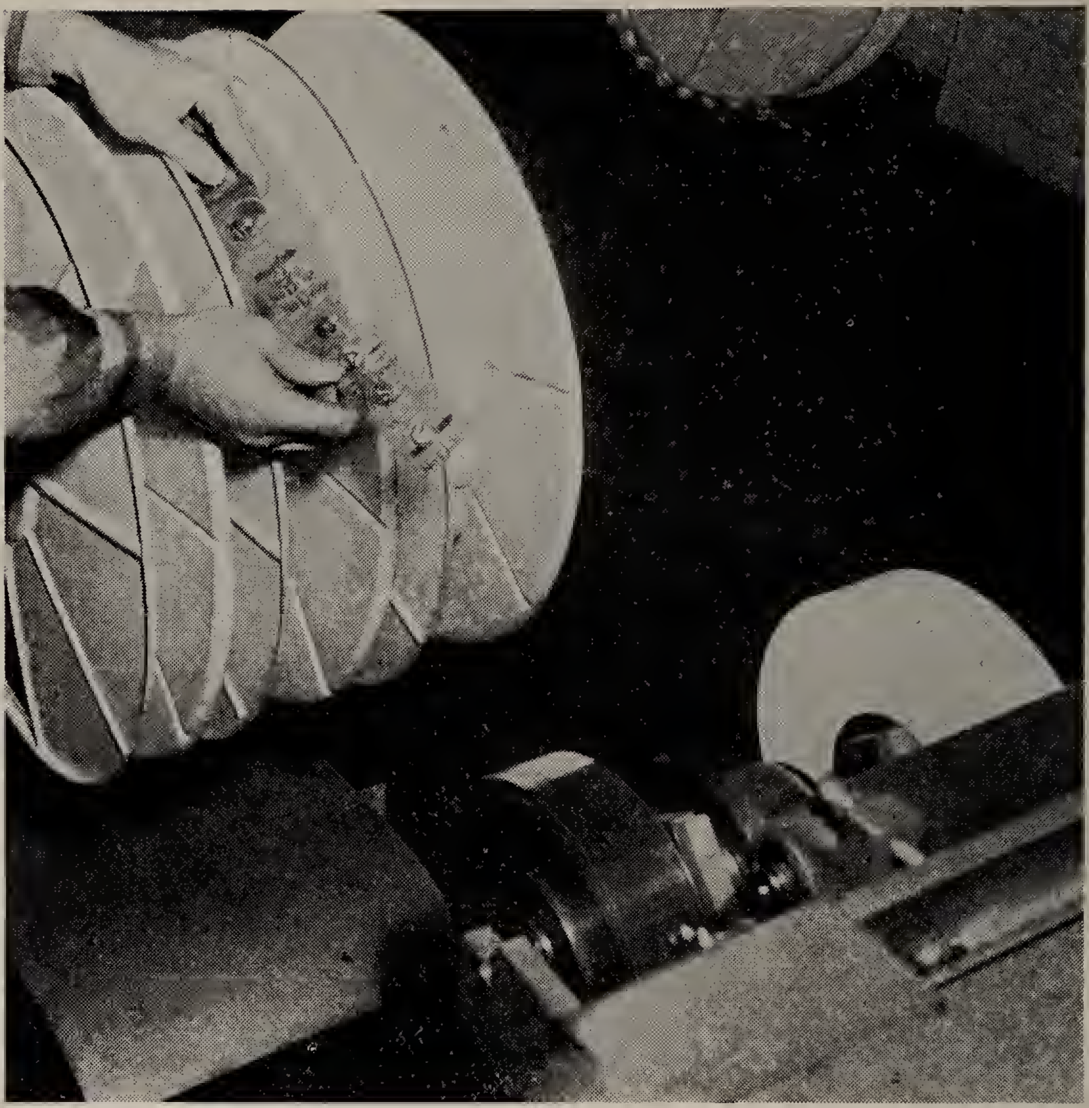


Figure 6–12

This machine requires an area 3 feet wide × 8 feet long × 44 inches high. The maximum roll width is 14 inches, but more than one ribbon may be fabricated simultaneously. Other sizes are available.

PRESSURE FORMING.

MANUFACTURER: AUTO-VAC COMPANY, BRIDGEPORT, CONN.

For forming difficult and tough materials requiring pressures higher than normal vacuums, this machine can operate at pressures as great as 250 psi.

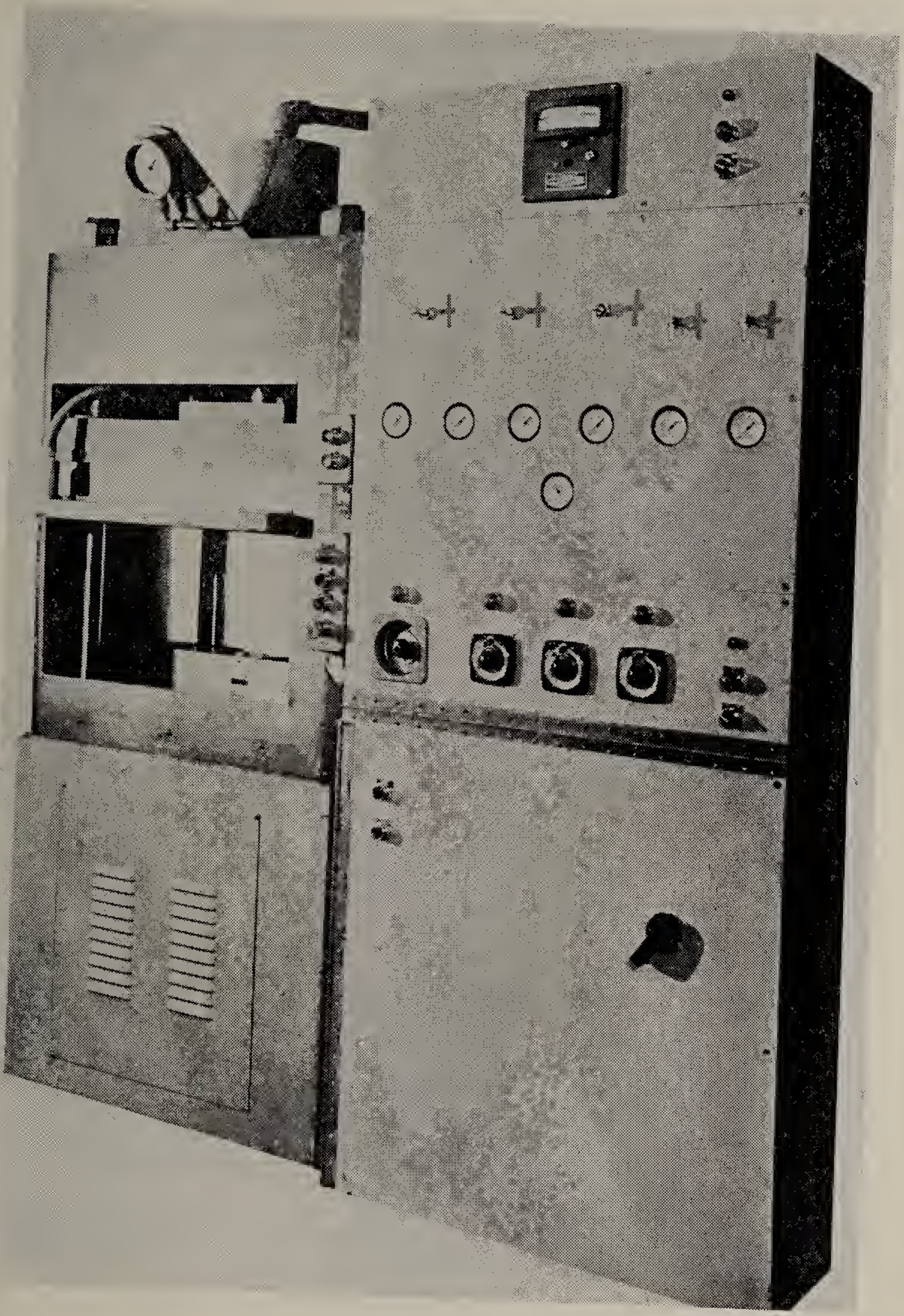


Figure 6–13

Featuring hydraulic clamping, it is completely automatic, having timed heating, cooling, dwell time, and blowing controlled by micro-second timers.

Complete cycle times as low as 10 seconds over-all can be performed on thin guage materials. Heavy guage plastics can also be pressure formed. Such materials as ABS types, "Mylar," oriented styrene, cast acrylic, polyvinyl chloride, and nylon can be formed with high detail.

Designed primarily as a high production unit it is complete with hydraulic pumps, tanks, and controls as well as a complete air and vacuum system.

Parts as large as 24 × 24 inches and 6 inches deep can be handled with rapid cycles. A manual roll feed is provided for advancing the materials.

## Continuous Forming

The continuous forming operation, as practiced by some people, takes the material directly from the extruder to a forming machine which moves with the web of plastic emerging from the die. Utilizing some of the heat from the extruded material, the machine adds enough heat to bring the material up to the forming temperature.

Used mainly with styrene copolymer sheets, the equipment may do straight forming, drape or plug forming. It is designed primarily for high-quantity production. After forming, the web may be cut and the material die cut by conventional means. The process has an advantage in that the manufacturer can reuse the scrap from the die cutting by regrinding it and re-extruding the material. In cases where there is a considerable area between the formations this type of forming has a competitive advantage since the material usage is less than on conventional machines.

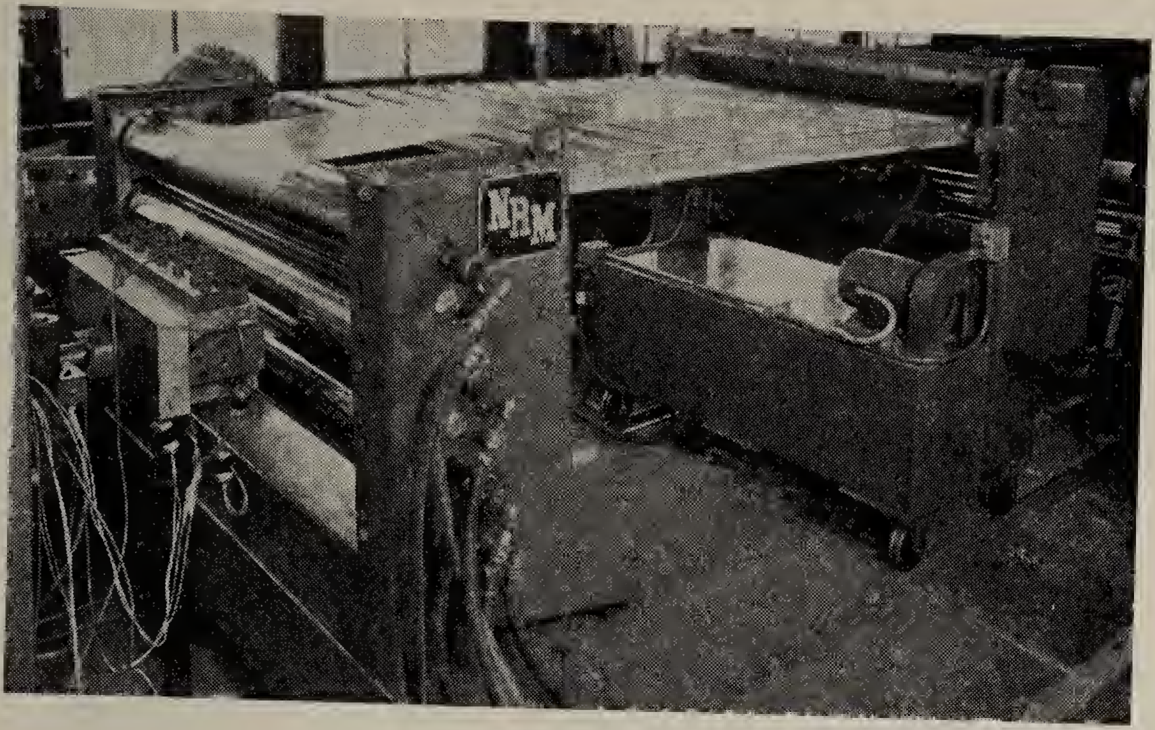


Figure 6–14

It is necessary to run this process continuously, usually 24 hours a day, to achieve economy since the extruder cannot be shut down and re-started easily, but must be re-checked and re-adjusted at every start. For long runs economies may be shown, especially on heavy gauge styrene.

The illustration here shows the extrusion of PVC sheet. At the left the extruder die is shown with the material emerging toward the right of the drawing. It passes between the second and third heated rolls of the take off and wraps around, emerging over the top roll.

In continuous forming, the equipment would be placed after the take-off equipment. The equipment at the right is set up for winding the extruded material on rolls.

## Drape Forming on Commercial Machines

### *Project: Proposed Baby Bassinet*

Drape forming using vacuum accounts for the major portion of products now produced by sheet forming. Draping the sheet just before applying the vacuum pre-stretches the plastic and reduces the thinning effect. The machine shown here is a general-purpose combination drape and straight vacuum machine. At the extreme right and extreme left of the panel are two-button safety starting buttons which clamp the sheet and start the automatic cycle.

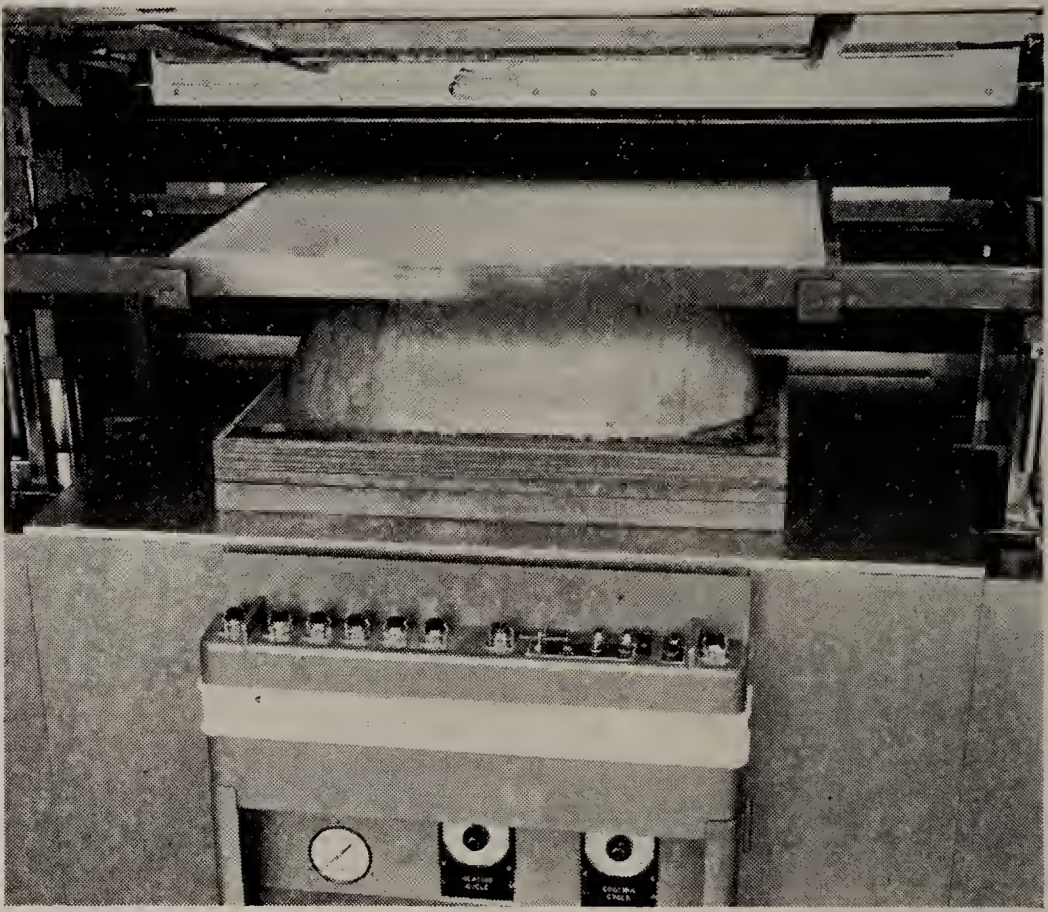


Figure 6–15

*Operation 1:* The ⅛ inch thick styrene copolymer sheet has been placed in the clamp frame between the top and bottom clamp. Note that in this position the sheet is held over the mold. After the heating cycle the sheet will be pulled down over the mold in the draping or pre-stretching cycle. A wood mold is used due to low production requirements.

*Operation 2:* The plastic sheet has been heated by the overhead heater which has automatically come forward and has been returned by an air cylinder. Note that the clamp has dropped

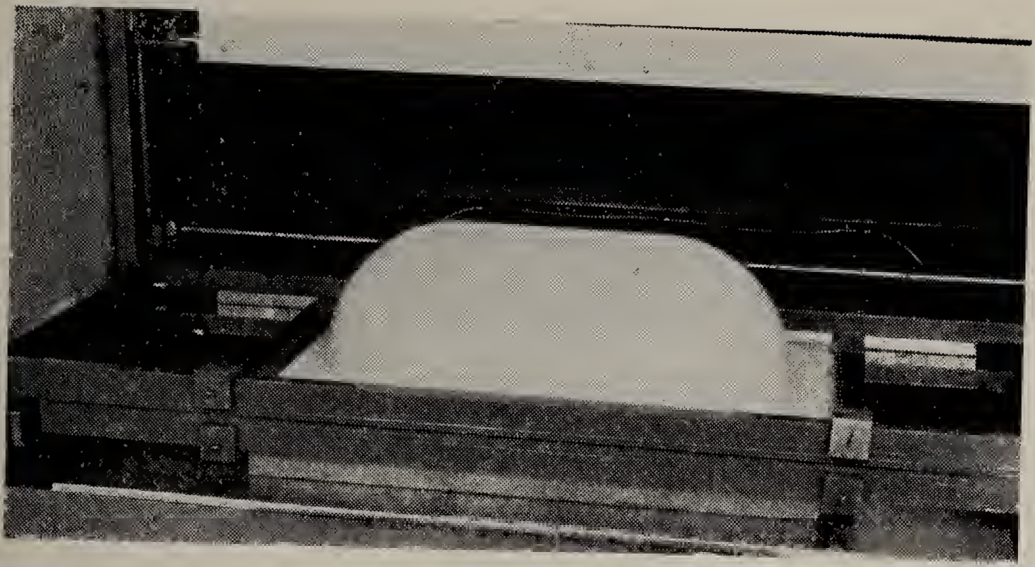


Figure 6–15 *cont'd*

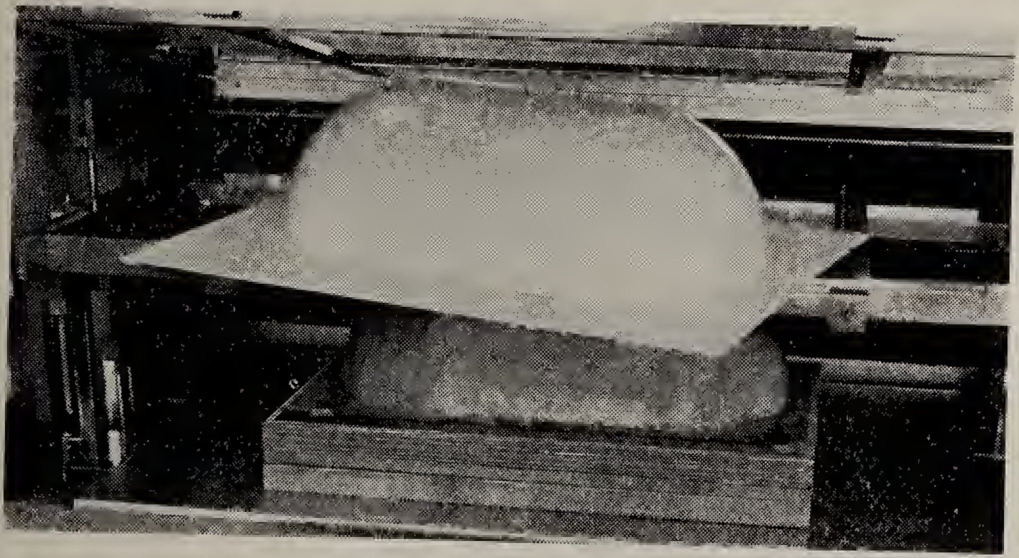


Figure 6–15 *cont'd*

to the level of the base of the mold, sealing there to allow the vacuum to pull the heat softened sheet to the contour of the mold. The cooling cycle clock now holds the plastic on the mold, with the vacuum on, until the part has cooled sufficiently to become rigid again.

*Operation 3:* The clamp frame, still holding the edges of the sheet, has moved upward pulling the plastic part away from the mold. At the top of this stroke the clamp separates allowing the completed product to be removed. The part will now be trimmed to size in a die cutting press and will be ready for assembly to the other components of the product.

## Straight Vacuum Forming on Commercial Machines

### *Project: Television Masks*

While combination straight vacuum and drape machines have supplanted the straight vacuum machines, there is still good work done by this process. As you may remember, straight vacuum uses vacuum alone to pull the heat softened sheet into a female mold. The process itself is quite simple, as follows:

*Operation 1:* The straight vacuum mold may make more than one part per cycle of the press. This mold produces three television masks of .080 inch thick styrene copolymer sheet at one time. The center section, which is cut out, is not polished and contains larger vacuum holes. The edge section is polished and has only fine vacuum holes. The hand clamping has weights at the rear to lift and clamp when the lock is released.

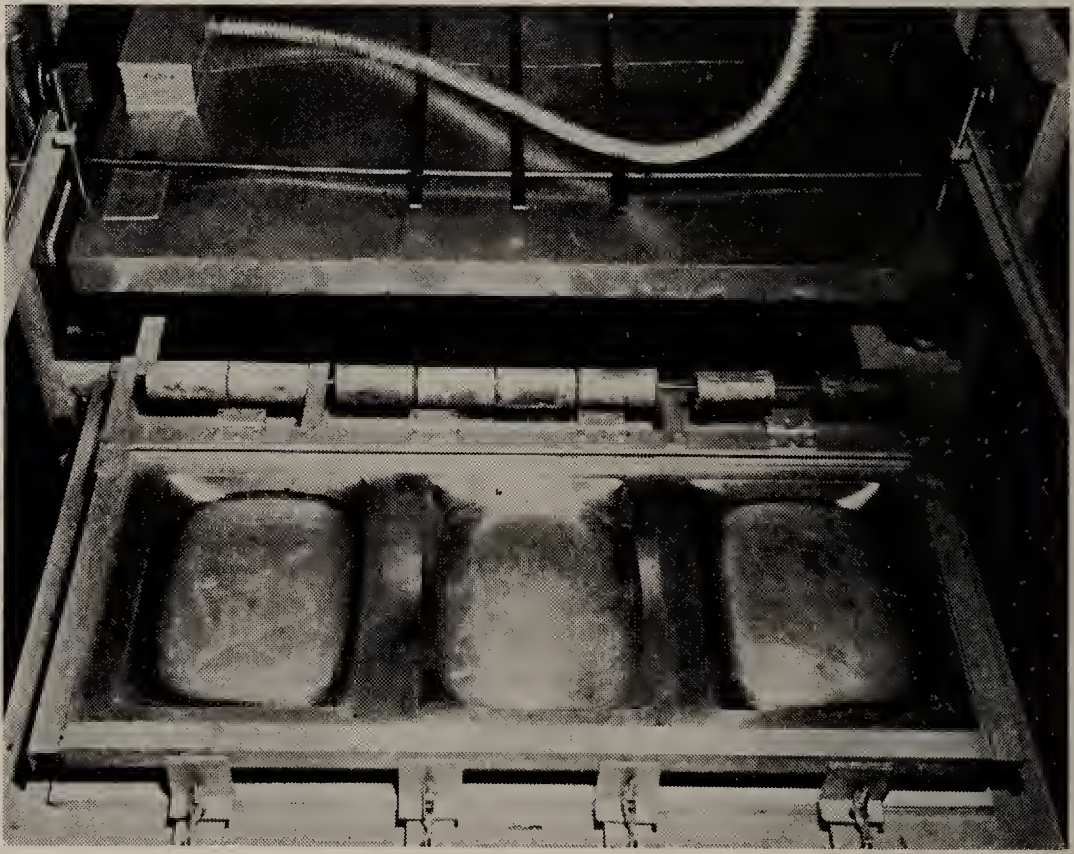


Figure 6–16

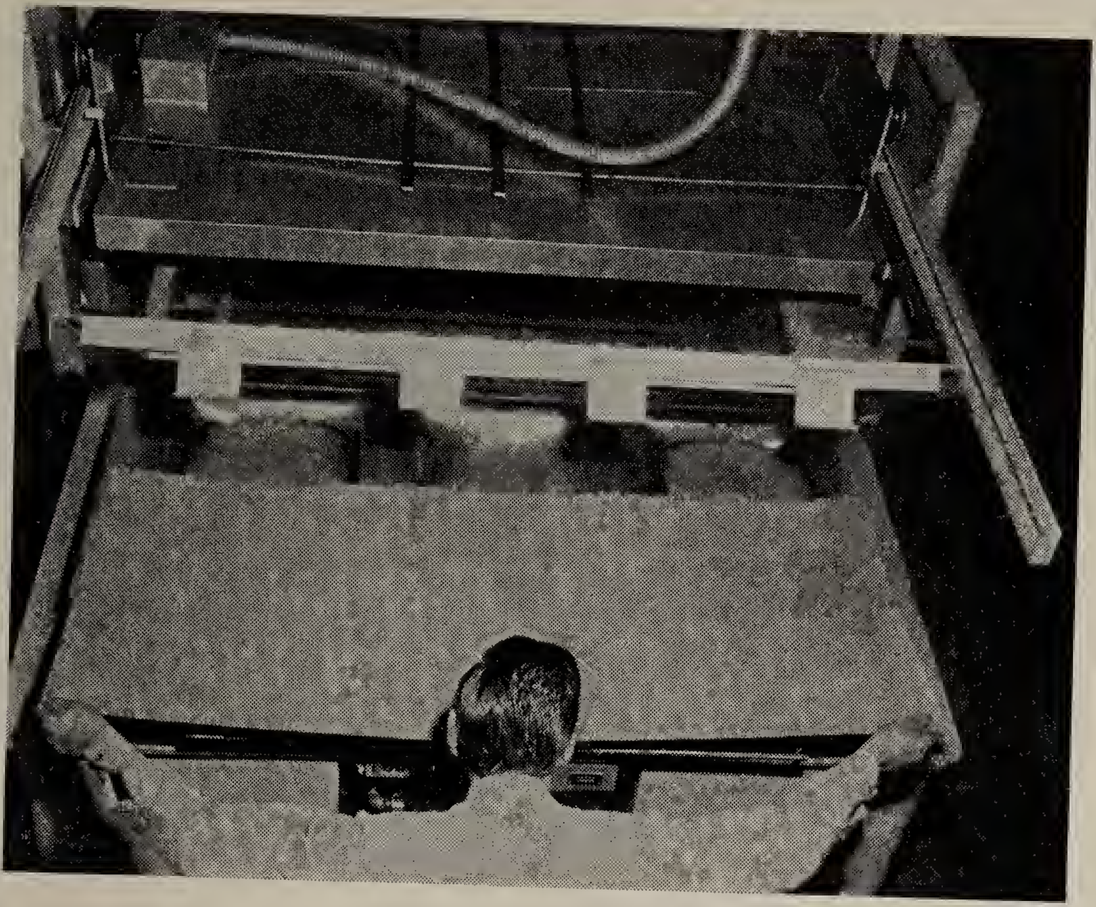


Figure 6–16 *cont'd*

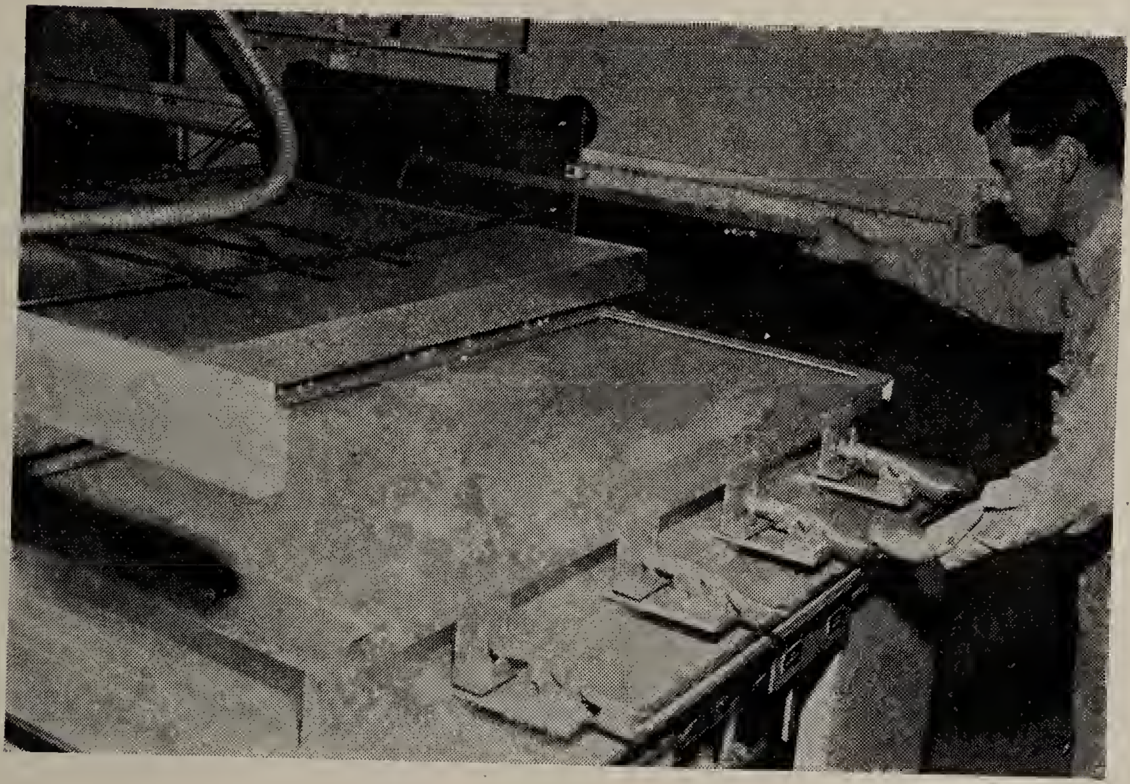


Figure 6–16 *cont'd*

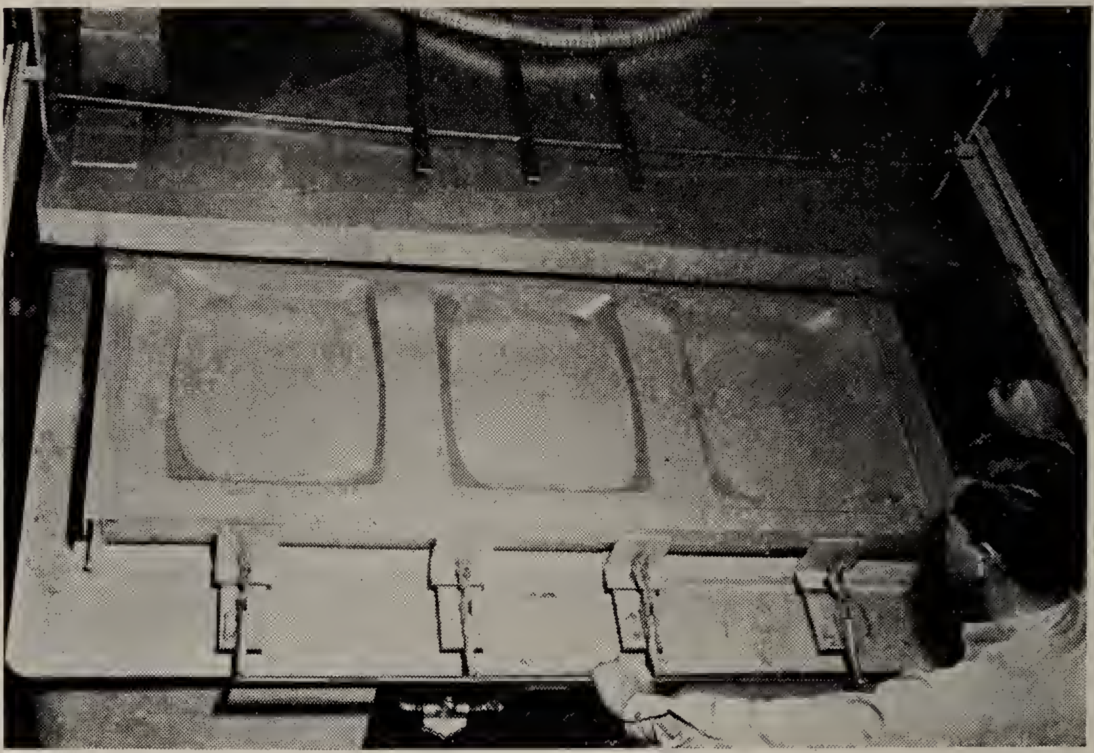


Figure 6–16 *cont'd*

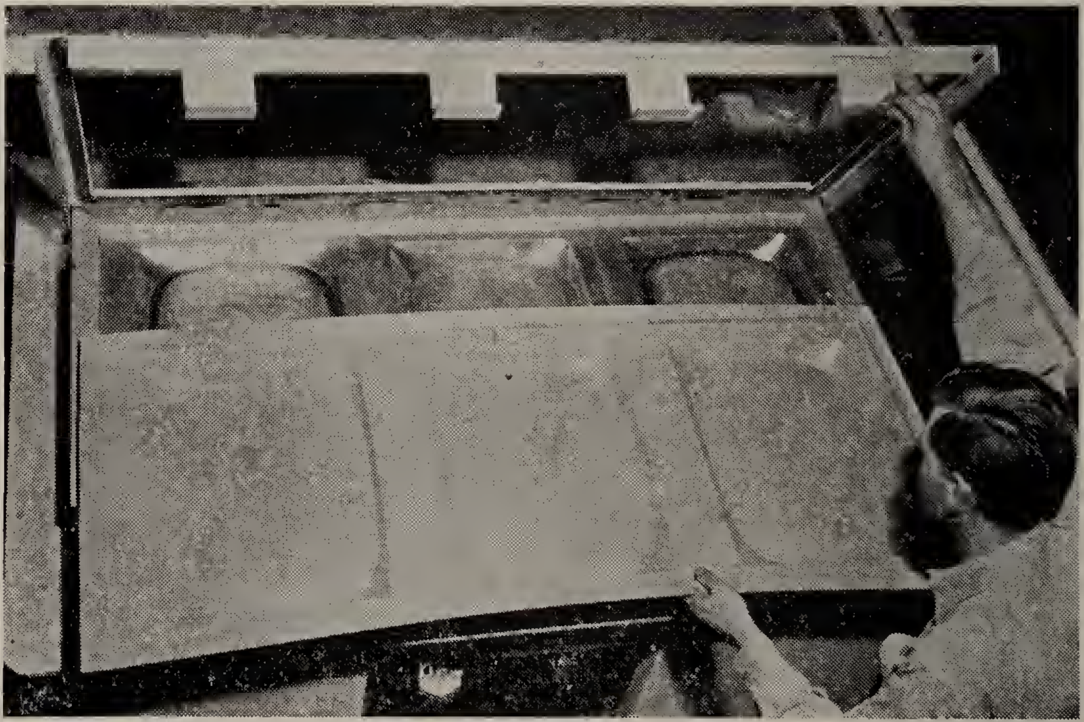


Figure 6–16 *cont'd*

*Operation 2:* A large sheet of styrene copolymer is loaded into the machine under the clamp. Edge pins locate the sheet in the proper position. The color of the plastic sheet has been selected to match the television cabinet design.

*Operation 3:* The clamp now holds the sheet firmly at the edges and provides a vacuum seal between the plastic and the mold. The heater when completely forward will trip the switch shown near the operator's right hand, starting the timed heating cycle.

*Operation 4:* At the end of the heating cycle (approximately 25 sec. on modern machines), the vacuum valve is opened, pulling the heat softened plastic to the contours of the mold. The heater, retracting from the heating position, will allow the plastic to cool and return to rigidity.

*Operation 5:* The part has now cooled sufficiently so that it will not deform if handled. The clamp is opened and the sheet removed. Later it will be cut up into three parts and the center die cut out to provide clearance for the picture tube.

## Air Blowing an Acrylic Aircraft Canopy

*Project:* Bell Aircraft Helicopter "Bubble"
*Material:* Rohm & Haas "Plexiglas"

Forming cast acrylic into aircraft enclosures is one of the most exacting and precise of all sheet forming operations. Not only must the shape of the product be exact, but it must also be optically perfect. Note that no mold, as such, is used over the entire surface since the slightest touch of the plastic sheet in the heat softened form would result in a blemish. Thickness variations must also be controlled to insure good strength.

*Operation 1:* The acrylic sheet has been heated to the proper forming temperature by being hung vertically in a precisely temperatured oven. It is now clamped in the mold at the edges. The plastic is approximately 5⁄16 inch thick and will retain its

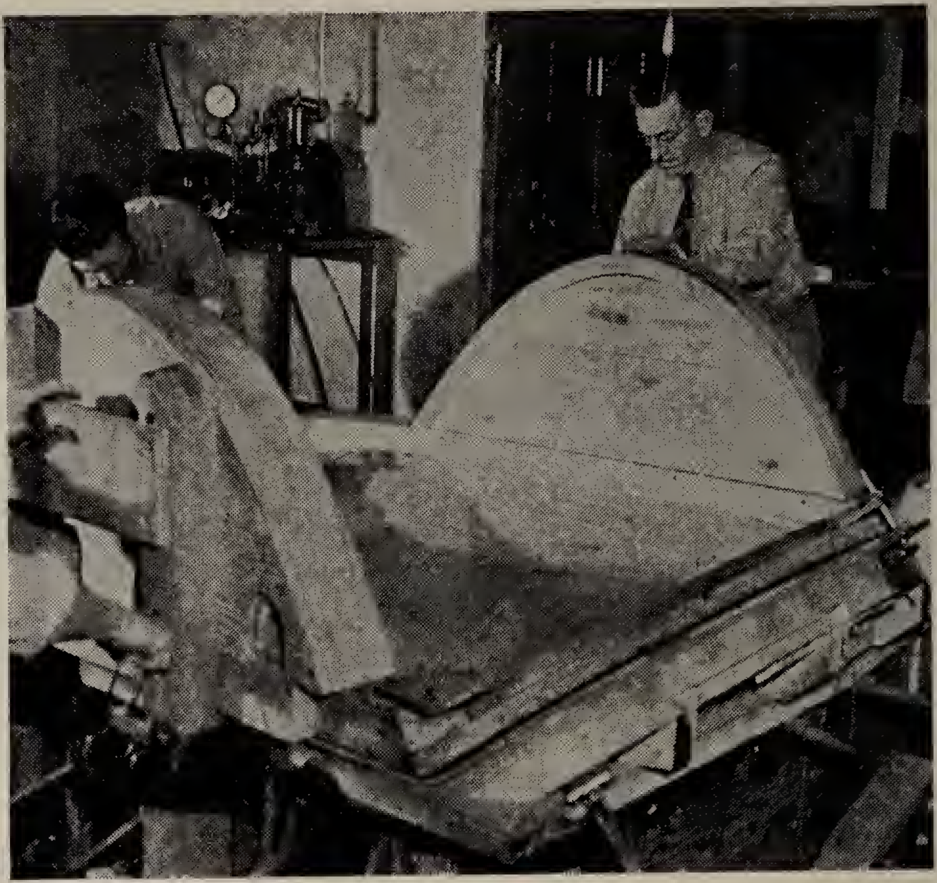
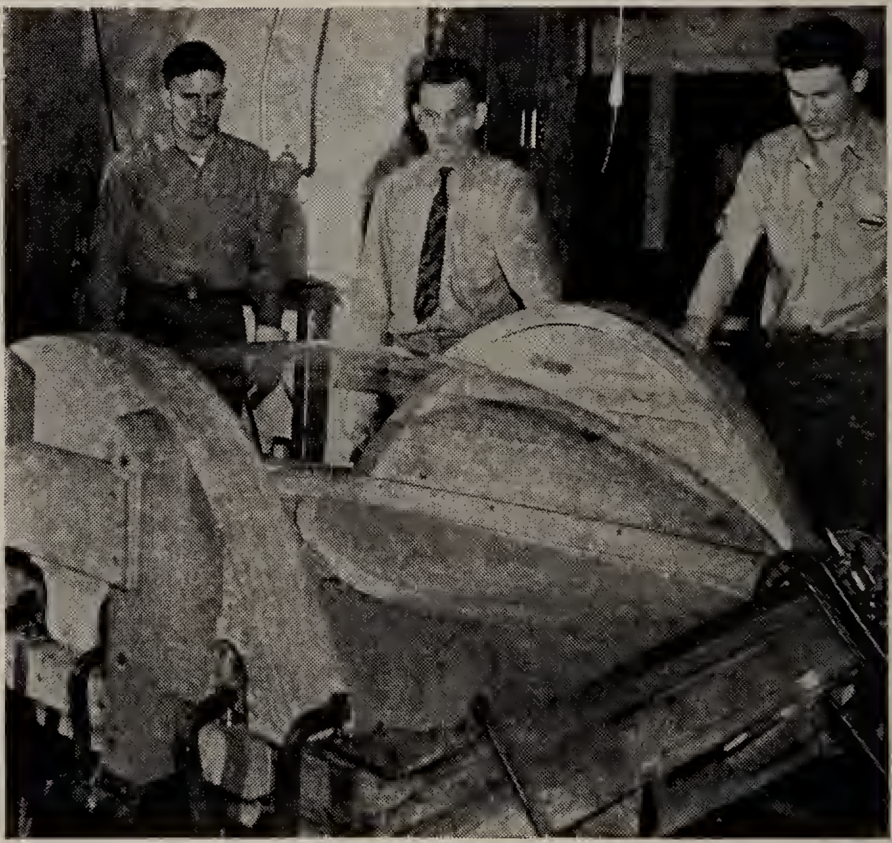


Figure 6–17



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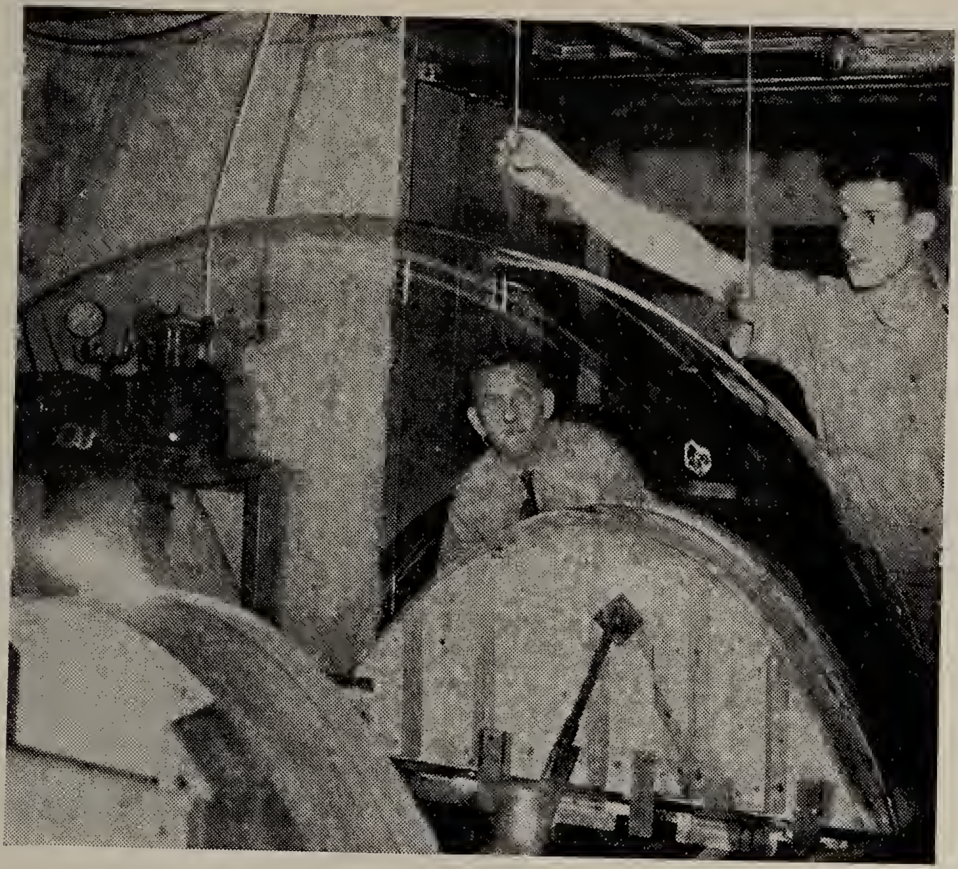

Figure 6–17 *cont'd*

heat for several minutes. This allows enough time to remove it from the oven and to clamp it in position.

*Operation 2:* The operator is now introducing air into the mold and the plastic sheet is expanding. Control of blowing is important to raise the plastic at the right speed so it will draw uniformly. Clamp edges hold the sheet and prevent air leakage. Note the clear transparency without blemishes.

*Operation 3:* Gaging now takes place and the operator with air controls admits or bleeds air to keep the acrylic formation at the correct form. Note that the interior of the mold at each side has been swung up to each side to form semi-circular sides of the "bubble." Careful cooling must now take place so that no internal stresses will occur. The part will now cool completely before being removed from the mold. Note the beautiful optical properties of the finished part. Any distortion would be unsatisfactory for an aircraft "bubble."

# 7. AUXILIARY EQUIPMENT

In addition to the sheet-forming machine, equipment is required for cutting the scrap or clamping edge from the finished product. While some sheet-forming machines also do the trimming, the majority of sheet formers use separate cutting or trimming machines. These are generally adapted from the machines used in the paper or metal industry and are therefore readily available. Sheet-formed parts are considerably deeper than most paper and metal products so that the trimming press must have a larger vertical die opening and, depending on the type of cutting, must have a longer stroke. In some cases the cost of the cutting equipment may be more than the sheet-forming machinery. However, the cutting dies are generally quite inexpensive.

In selecting a cutting press the first consideration must be given to the size of the product and to the type and thickness of the plastic material, since the cost of the trimming press and the cost of the trimming die increase as the size of the part increases. It is also important to realize that the type of cutting used on a small part will not of necessity work well on a large part.

To evaluate the various cutting techniques properly we will first describe the types of presses, keeping in mind that different die techniques can be used with these as required by the product.

A popular inexpensive type of trimming press, is called a "clicker." This press has a flat platen covered with a thick laminated wood block (up to 5 inches thick) or with a heavy 1 inch hard-rubber pad which acts as the cutting surface. The part to be cut is laid on this surface and a steel rule die is placed on top of the part, with the cutting edge resting on the

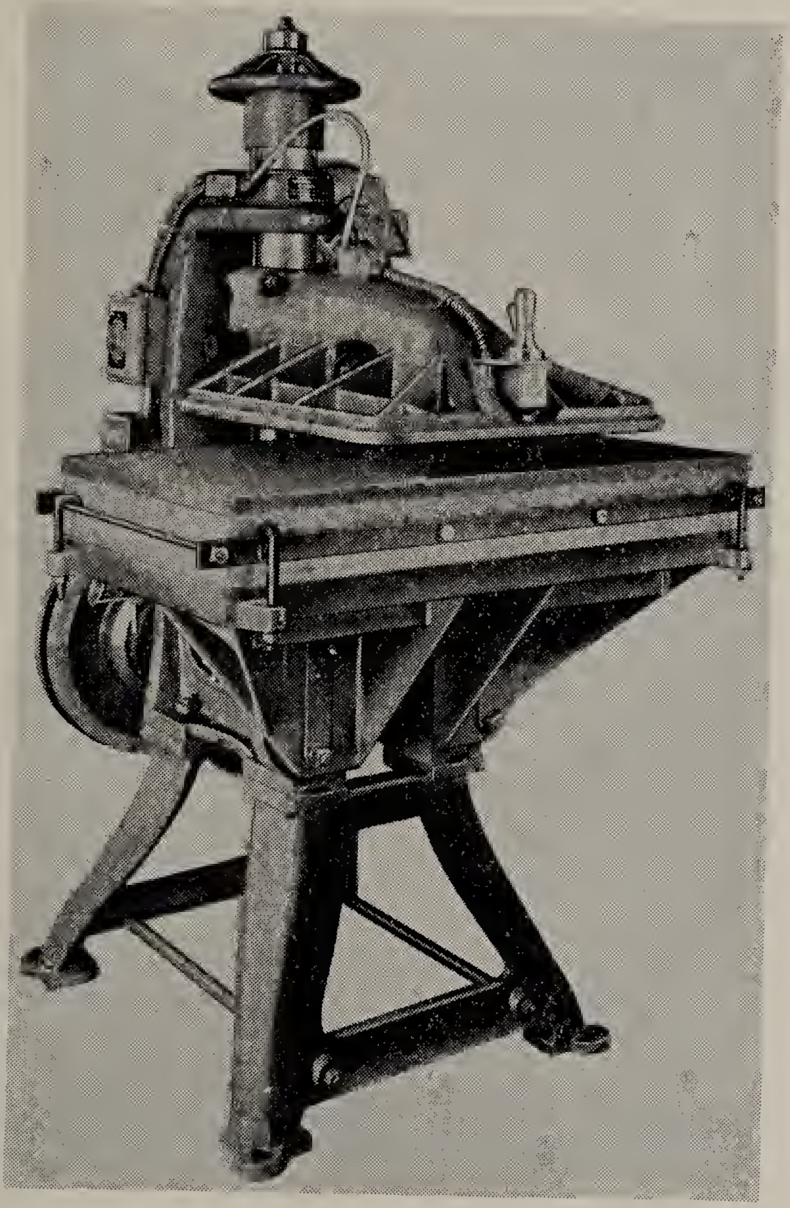

Figure 7–1. Clicker die cutting press. This press is known as a clicker because of the fast rap the traveling head gives to the die. In the above picture, the head is swung over the work ready for action. The handle at the front of the top head is the release mechanism. The bottom block is made of maple approximately 4 in. thick with a synthetic 1 in. thick top layer. When the blocks become heavily scored, they may be reversed. When both sides become heavily scored, they may be replaned. Figures 7–1 a, b and c show the press in operation. (*Courtesy Herman Schwabe, Inc.*)

lip to be trimmed. An overhead platen swings around a center post in which the motorized drive is located. When positioned over the top of the die the handle containing the release mechanism is pressed and the overhead platen gives a sharp rap to the top of the die, driving it through the plastic against the wood or rubber plate and trimming the piece. The stroke is short, usually only 1 inch, and the head must be turned away from the working area to remove the part. If the part is difficult to cut it is possible to give more than one rap to the

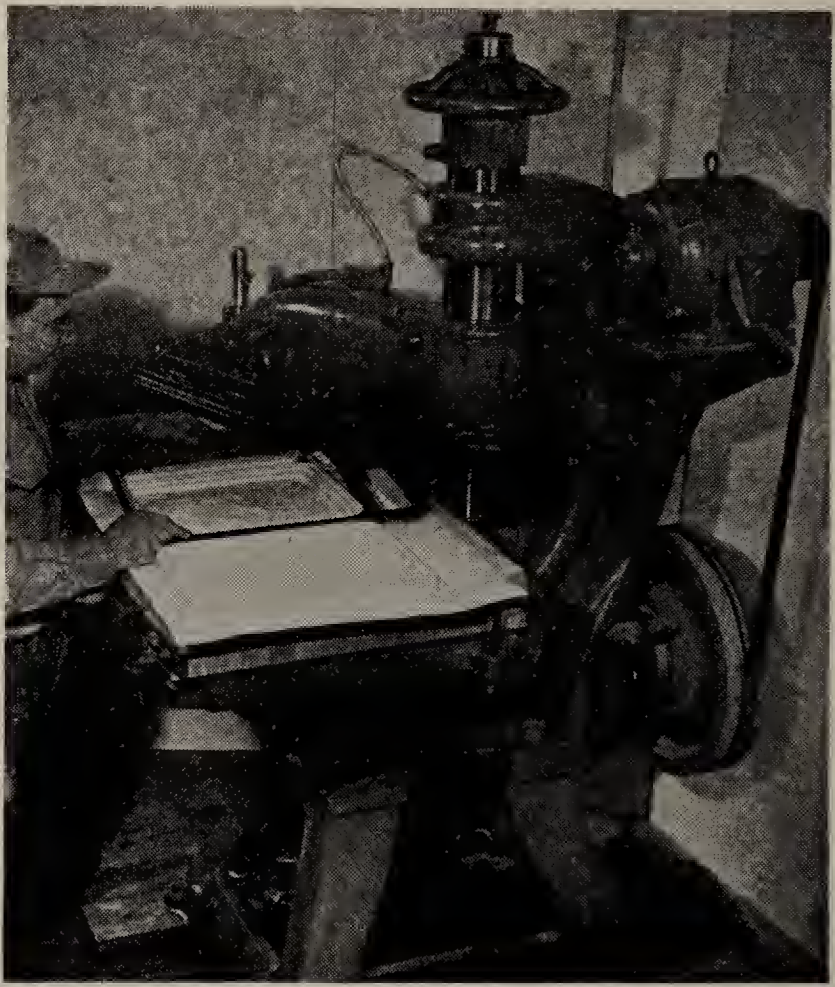

Figure 7–1 a. The first step in operating a clicker press is to place the sheet-formed plastic flat on the bed, which in this case is a maple block. The steel rule die is now being placed in position with the cutting edge on top of the plastic. Note the head of the machine is swung out of the way to permit movement of the die and plastic. (*Courtesy Herman Schwabe, Inc.*)

die to drive it through the plastic. If the part is large, so that the top platen will not hit the entire die top, it may be swung against each side successively.

With the natural draft of the sheet-formed parts they may be stacked easily so that several may be cut with one rap of the clicker head. While the cutting block is usually of a hard wood such as maple, or a composition material, a metal pad is sometimes preferred. An aluminum or brass plate will usually give good results.

Some types of product will allow the block to be fastened to

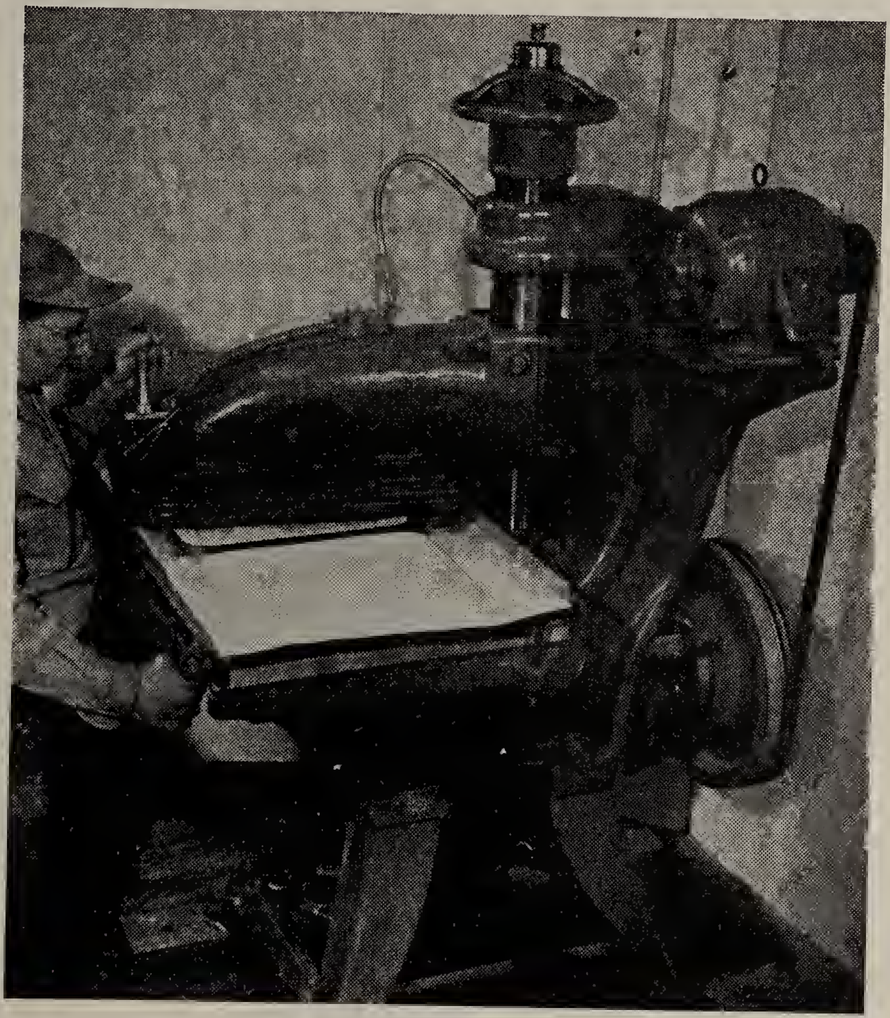

Figure 7–1 b. The operator has swung the head flat until it is directly on top of the steel rule die. With his left hand he presses a clutch release and the head will drive the steel rule die through the plastic, shearing it off against the maple block. The parts can be stacked to cut more than one thickness. (*Courtesy Herman Schwabe, Inc.*)

the swivel platen and the cutting die inverted on the bottom platen. When this is done the die is not picked up after each cut since the parts are removed from the upward section of the die. This is especially desirable where the cutting die is heavy.

The clicker or die cutting press usually has a platen area approximately 20 × 40 inches and a cutting head 24 inches wide. Cutting heads of 12 and 18 inches are also available for smaller work. To cut the entire area of the table more than one stroke must be used. For parts wider than 40 inches two

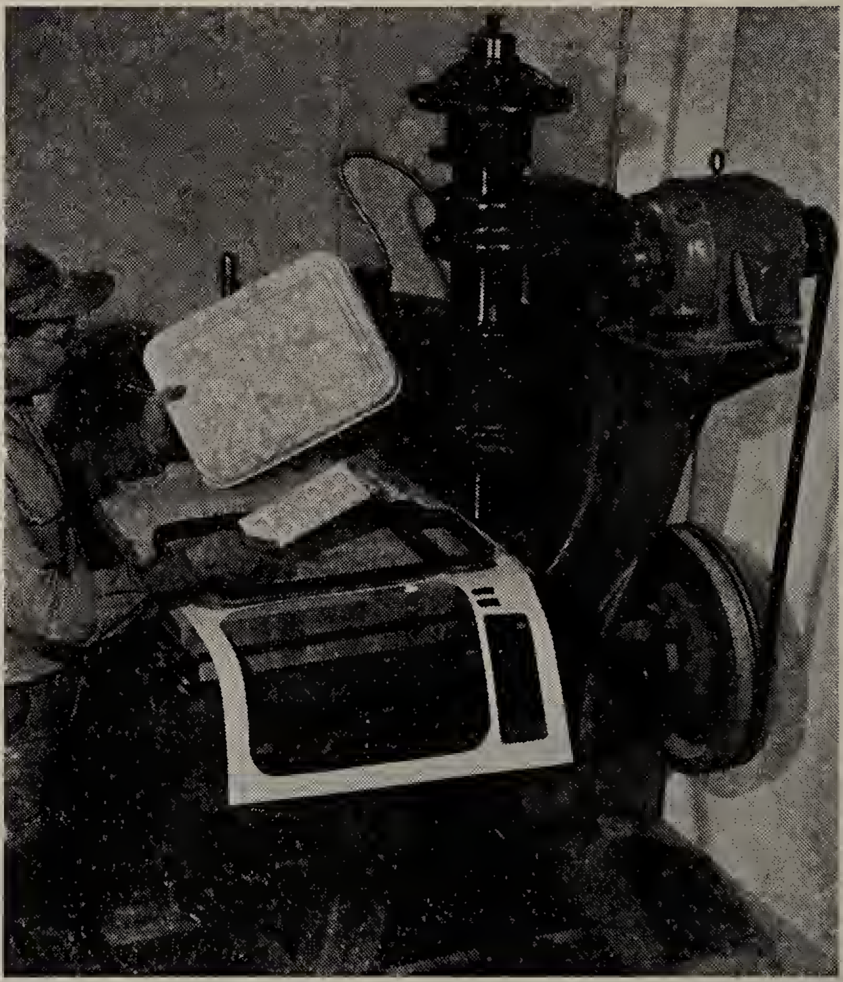

Figure 7–1 c. The operator has swung the head out of the way and the cut pieces can be removed from the die. Note that four parts have been cut from the sheet at one rap of the clicker. The operator will now move the die to the third section of the sheet and repeat the operation. If the part were smaller, a die with three sections might be used to cut the entire sheet without removing the die. (*Courtesy Herman Schwabe, Inc.*)

clickers are sometimes mounted facing each other with a common table 24 × 54 inches mounted between them. The mechanisms are synchronized to operate simultaneously and larger parts may be die cut.

Another popular die press is the crank type, common in both the paper and metal industries. This type of press has a fixed bottom platen with a guided platen directly over it. The die block with the part to be cut and the die are moved in and out of the press on a roller. On some work of medium depth it is

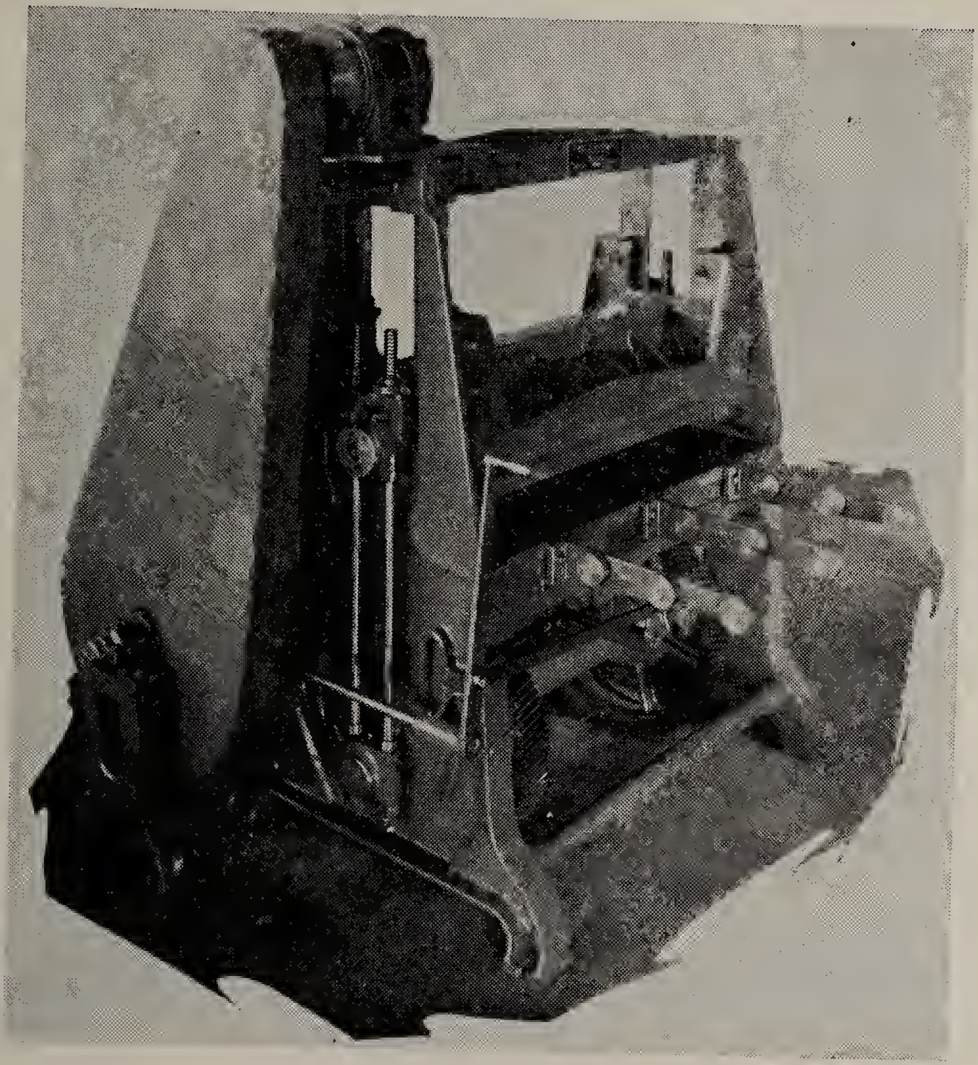

Figure 7–2. Crank type die press. Used for cutting out sheet-formed parts this press can handle most plastics up to ⅛ in. thick. Model shown has a bed size of 44 × 22 in. with a 5 in. stroke. A special twin disc clutch insures a clean cut. The die block slides in and out on rollers. Larger models are available up to 60 × 26 in. platen size. (*Courtesy T. W. & C. B. Sheridan Co.*)

possible to set up the die permanently in the press and to place the plastic parts in the die, under the moving platen. This press is available in many sizes and any tonnage so that it can be used on heavy work. The guided platen keeps the die and cutting platen in perfect alignment, thereby cutting uniformly.

Its operation is similar to the clicker mentioned previously but it handles larger and thicker parts and cuts more accurately. Several different types of dies are used with the above machines, but essentially they are all sharp blades which cut through the plastic to the cutting block. One of the simplest cutting dies is made by bending steel rule die stock into the shape of the product to be cut, and inserting it into a ply-

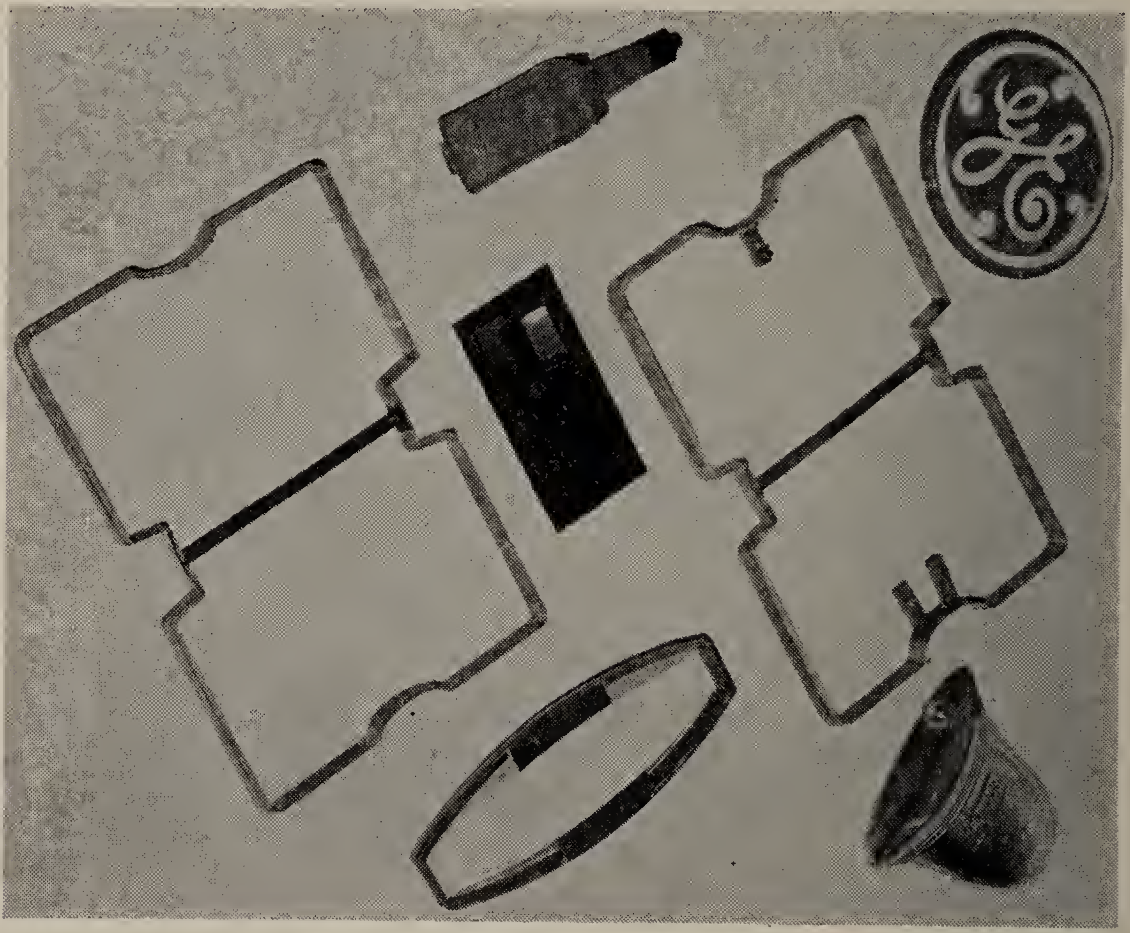

Figure 7–3. Typical steel rule dies and sheet-formed products cut by this method. Best suited to low-profile work, these dies are inexpensive. Used with a die press or clicker, sometimes several parts can be cut at one stroke. (*Courtesy Western Supplies Co.*)

wood back cut to the same shape. The joints may or may not be brazed although some joints may just be matched. Rubber pads between the cutting edges will push the scrap and part out of the die after cutting. Since the blade only extends about ¼ inch beyond the plywood, it is limited

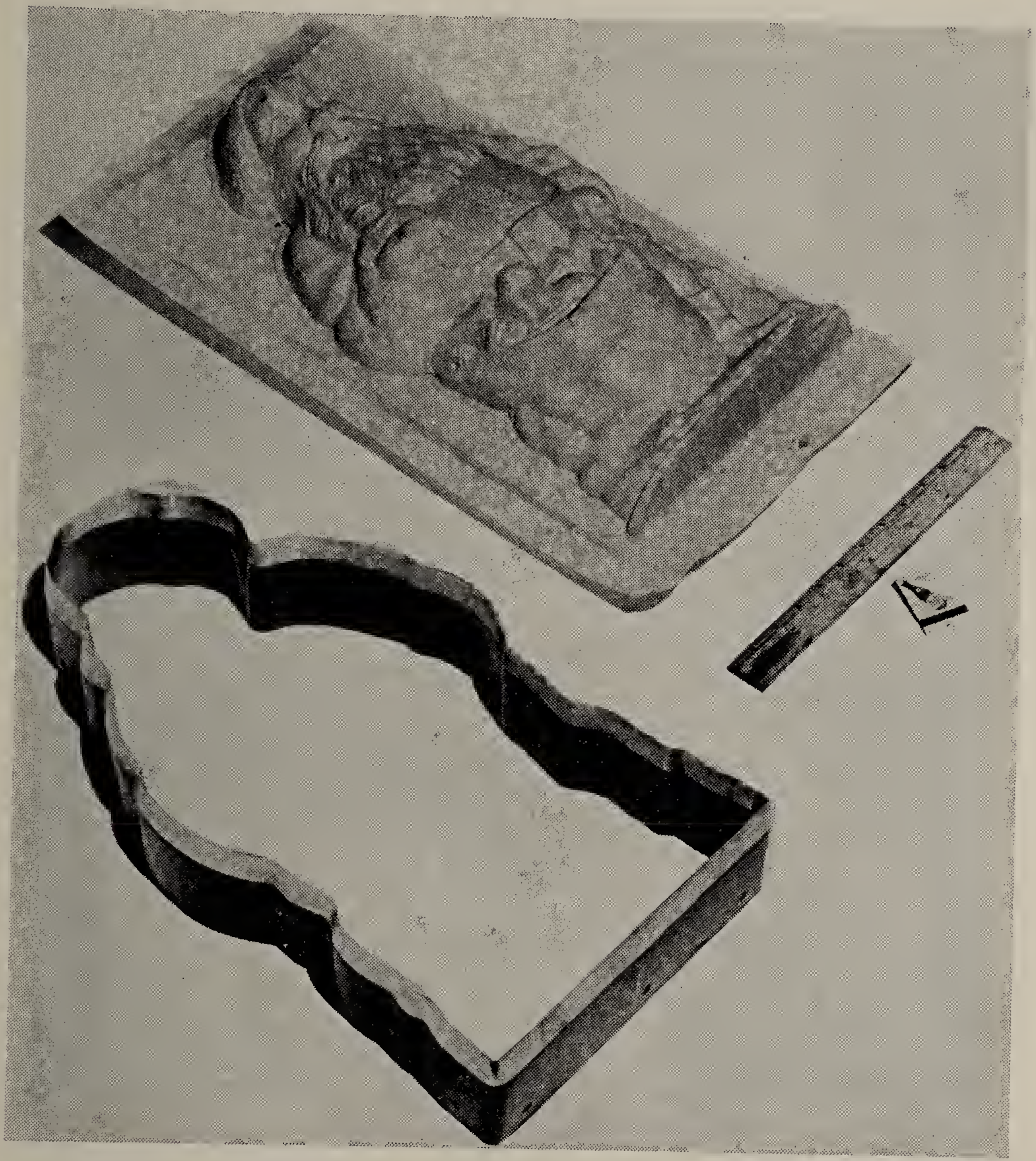

Figure 7–4. High die. For deeper work the high die shown is forged and welded into the correct form. The edge is sharp and the die can take a heavy blow. Such dies last a considerable time before they require sharpening. The die shown is over 30 in. long and 4 in. deep. (*Courtesy Western Supplies Co.*)

to cutting shallow parts. Sometimes openings are cut in the plywood to clear high parts if the design permits. Parts may also be cut from the bottom of the flange of a plastic part with the raised part away from the die, but this requires a matching die block. In order to cut satisfactorily this die block requires frequent planing. Normally, the die is moved around on the cutting block so that it does not always land in the same spot, thus the die block will not require replaning for a considerable time.

For deeper and heavier parts a heavier steel rule blade is used. This may be up to 2 inches high and is bent to shape, and the corners are welded or brazed. It is fairly light and may be

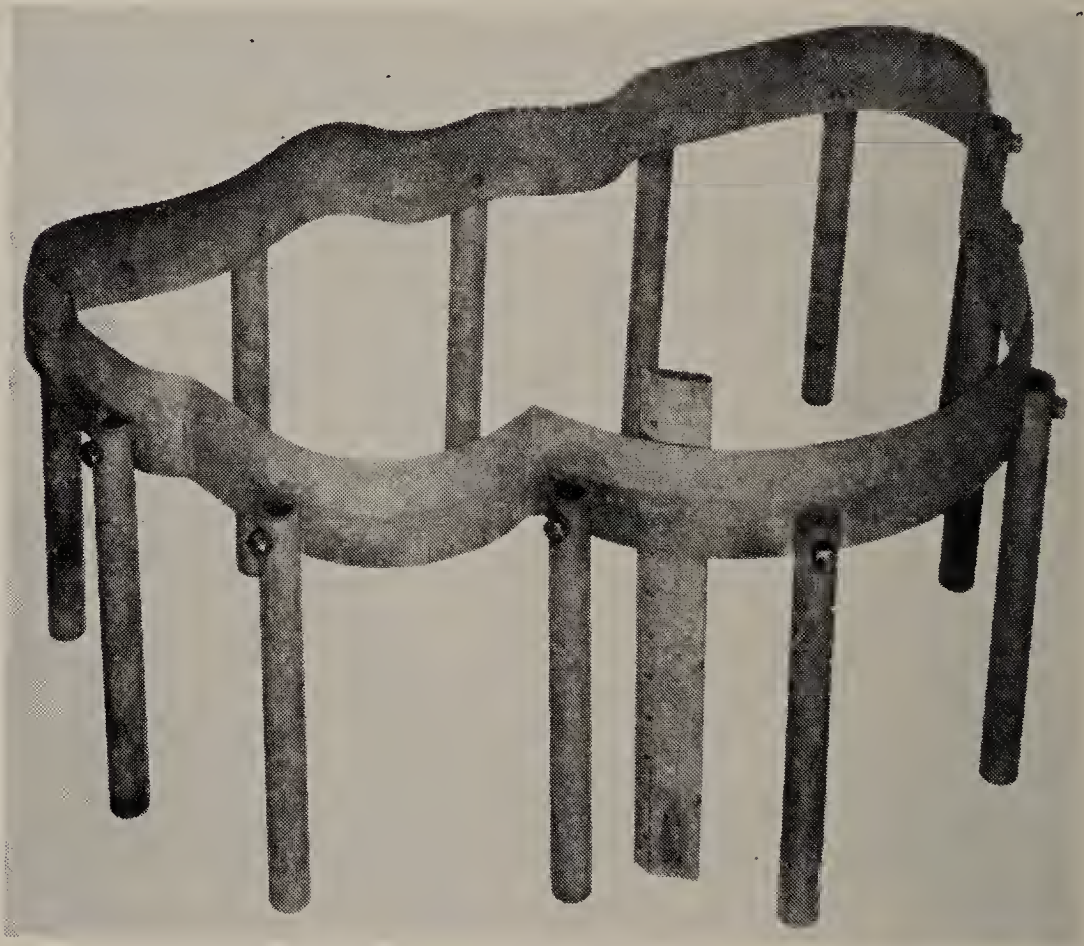

Figure 7–5. High die for deep parts. For very deep parts, legs or extensions are added to the high die. The above die will cut a part 12 in. deep. The use of extensions makes the entire die lighter and easier to handle and, therefore, less expensive. (*Courtesy Western Supplies Co.*)

handled easily. The die may have springs or rubber pads mounted to eject the part.

When the product is still thicker and deeper a die is constructed by forging a steel strip to the desired shape. This is usually ¼ inch thick and may be considerably heavier than the previous die. It has an exceedingly long life and may be resharpened. When the part is very deep, several pads may be added to increase the die height and decrease the weight.

To cut products having a contoured edge a matching die and die block must be used. Usually the two are used in a die set with guide pins so that perfect alignment is maintained. The die block is metal instead of wood since the cutting die always lands in the same spot. The assembled unit with the plastic between is slid into the press betwen the platens, which are

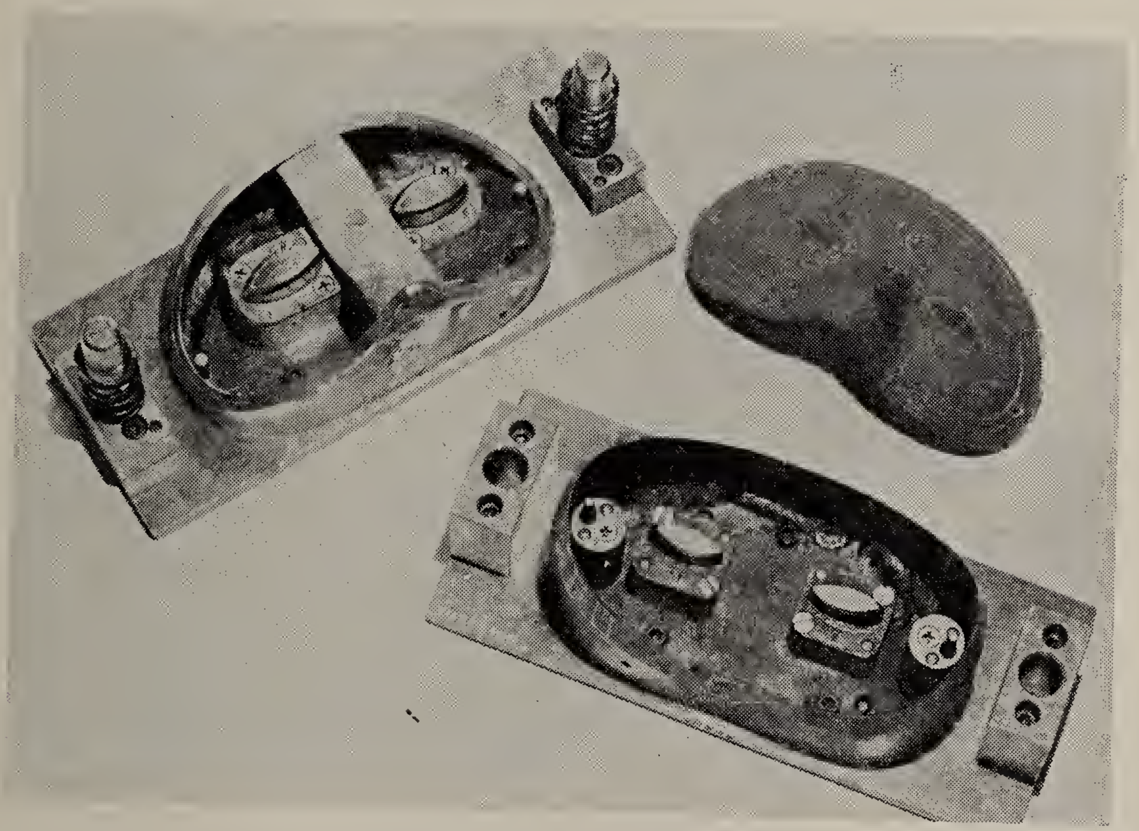

Figure 7–6. Contour cutting. For die cutting where the cutting edge is not on one level, a matching contour die and base are used. Guide pins are required to maintain perfect alignment. Note that the holes for the eyes and for the string are perforated at the same time. (*Courtesy Western Supplies Co.*)

set so the die will just reach the die block. Thus there is little wear on the die block, and the unit can be mounted permanently in the press so that only the plastic part is handled in the press.

In describing the above machines and dies, it is necessary to realize that the thicker the material the higher will be the pressure required to shear it through and that the number of inches of cut are limited by the tonnage of the press.

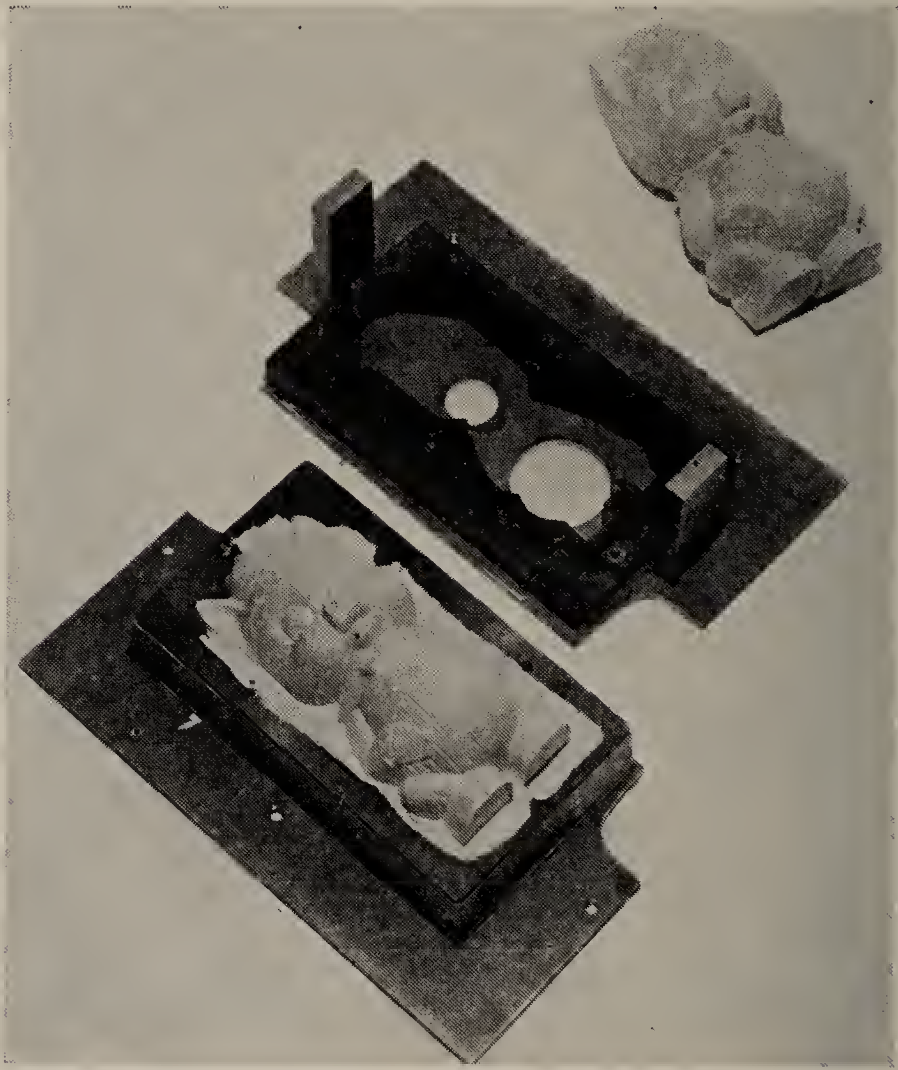

Figure 7–7. Matching die. For matching plastic parts, such as the front and back on this toy, the die cutting must be exact. This requires a fixture to support the plastic and a close fitting die. The die is inverted over the fixture with the plastic in place and the entire unit slid between the platens of a die press or clicker for cutting. (*Courtesy Western Supplies Co.*)

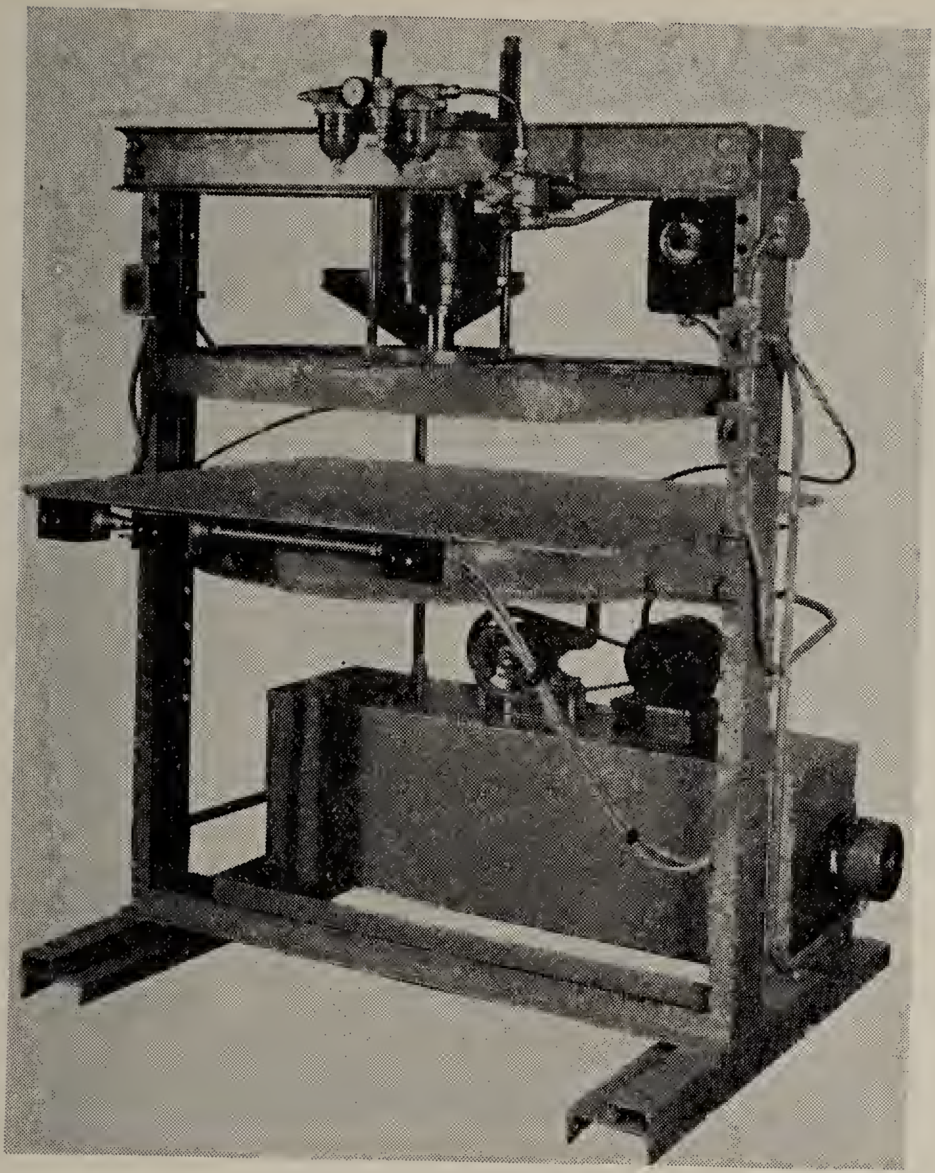

Figure 7–8. Hot die trimming press with a single cylinder. The timer at upper right corner regulates time of dwell during cutting. Hot oil tank at bottom supplies heat to dies. Press size is 24 × 36 in. (*Courtesy Boston Cutting Die Co.*)

In order to avoid going to extremely heavy and expensive presses, a type of cutting known as "hot die" cutting is used. If the same steel rule dies, described previously, were heated we would find that the cutting pressure would be reduced since the die would half cut and half melt its way through the plastic. Instead of using a press which has a heavy pressure, one with an air or hydraulic cylinder is used and direct pressure applied

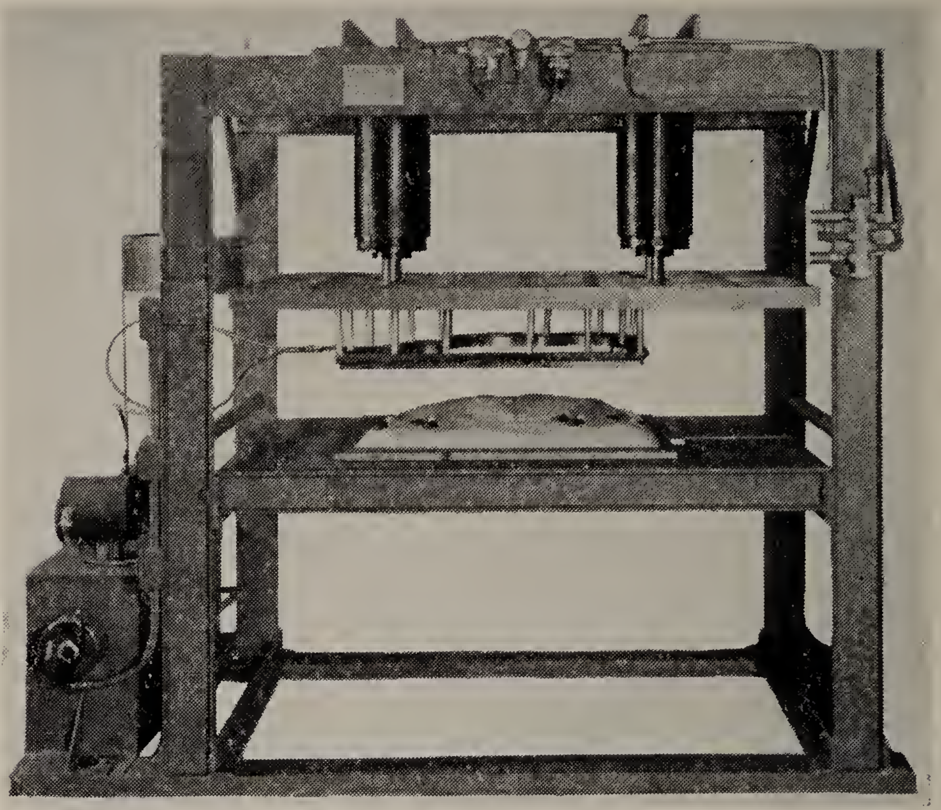

Figure 7–9. Hot die trimming press. Large size trimming press requires two air cylinders for pressure. Note high die with extension supports to provide necessary height to clear plastic product. Hot oil tubes from left supply heat up to 550 degrees. Press size is 30 × 50 in. (*Courtesy Boston Cutting Die Co.*)

to the cutting knife until it shears its way through to the cutting block. In this type of press a large platen is available at low cost since the pressure required is low.

The dies may be heated by means of a thin tubing arranged around the outline of the die. Hot oil is run through this tubing to heat it to a predetermined temperature. Dies may also be heated by mounting them to a plate which is heated conventionally by electric resistance strips or similar components. This type of heating is limited to smaller products since the further the cutting edge is away from the heating element, the less uniform will be the cutting.

The die is usually mounted to the moving platen, and the part is placed on top of the fixed platen. This should be of

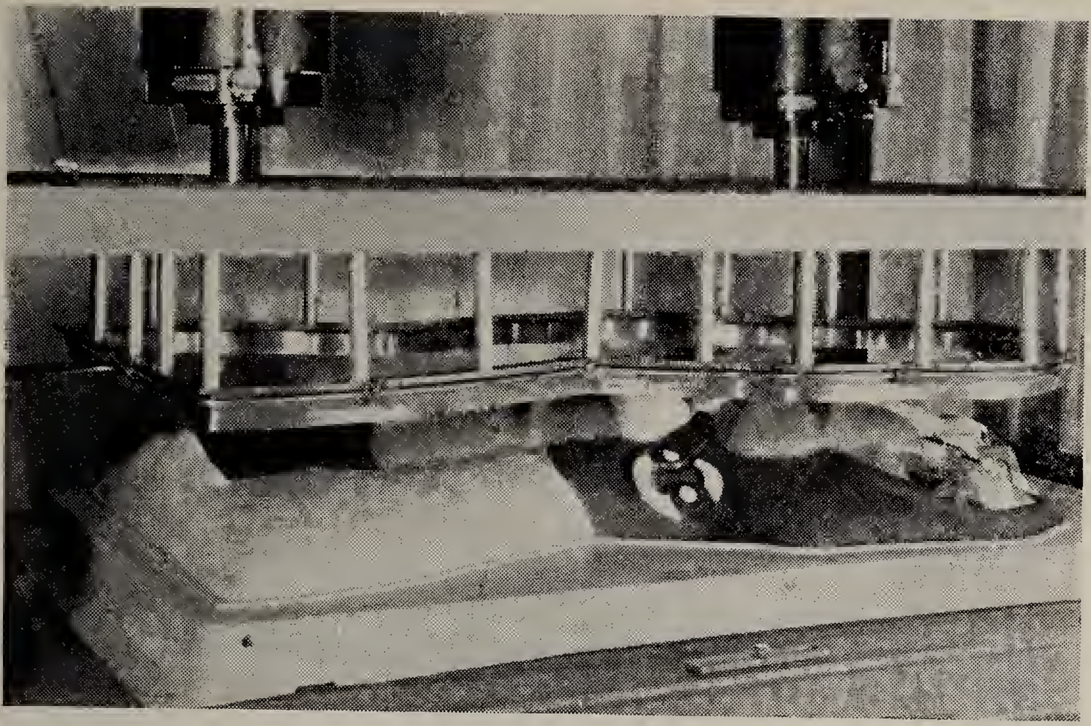

Figure 7–10. Hot die cutting. Photograph shows part over 48 in. long just prior to hot die cutting. Hot die has sharp edge and is heated by tubing shown attached to die. Block under the plastic is flat masonite. Air cylinders drive the die down until it hits the plastic where it rests under pressure. Heat and pressure will drive the sharp die through the plastic in a matter of several seconds. (*Courtesy Boston Cutting Die Co.*)

some nonmetallic material so that the heat is not drawn away from the cutting blade. The moving platen is then activated until the cutting knife presses on top of the plastic and rests there until the heat has sufficiently softened it so that the blade will shear to the fixed platen. This takes in the order of 2 to 3 seconds for sheets approximately .060 inch thick. The product may have an improved edge when this type of cutting is used since the heat will slightly round all the sharp edges.

The costs are slightly higher for this type of die but longer life results due to the lower pressures required.

For extremely accurate and fine cutting, stamping tools similar to those used in the metal industry are required. In this type of stamping both a male punch and a female die are used and the punch shears the plastic into the die. These dies are of all metal steel tool construction and are accurately ground and machined. They are mounted in a die set to give perfect alignment. Usually some sort of a spring, strip or plate is incorporated to remove the finished part from the die.

Regular metal cutting presses are used such as open side crank presses, guided platen crank presses, and hydraulic guided platen presses. When large size presses are required, such as are used to perforate and stamp out refrigerator door liners, hydraulic presses are usually more economical. These can be constructed with the long strokes required and the large

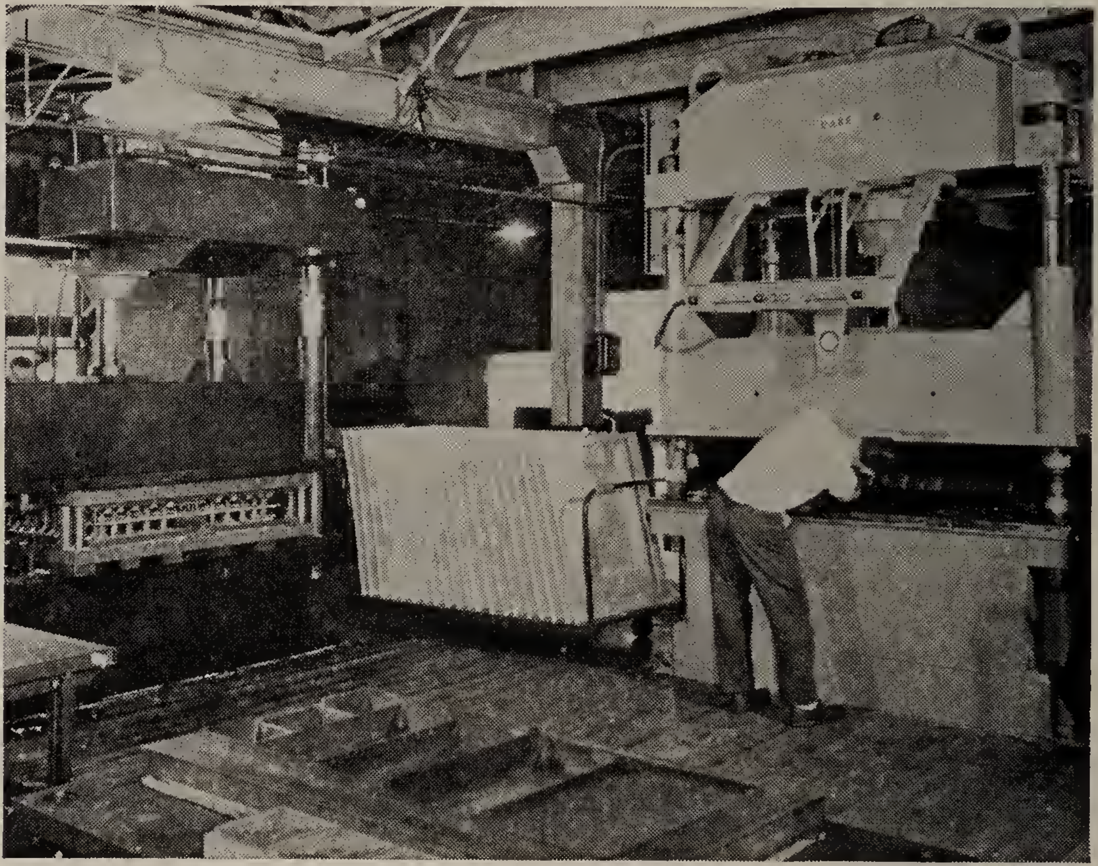

Figure 7–11. A typical set up for trimming refrigerator parts utilizing two Dake hydraulic presses. Pumps and controls are overhead, keeping the floor space clear. 150 ton down cutting press has guided platens. Press at left has door liner just being trimmed and the holes perforated. Completed parts are stacked at the right. In the foreground is a typical cast aluminum mold for a refrigerator door liner. Press at right is being prepared for trimming and perforating tool. (*Courtesy Dake Engine Co.; Installation, Kent Plastics*)

die openings at a lower cost than crank presses. They usually range from 75 to 150 tons. For example, a typical press for a refrigerator door would be rated at 150 tons, have a platen area of approximately 36 × 80 inches, and a stroke of 20 inches.

The operation of this press may be different in individual plants. Some people prefer to place the cutting equipment directly adjacent to the forming press so that the same operator can run both machines. It must be remembered however that the sheet-formed parts must be allowed to cool to close to room

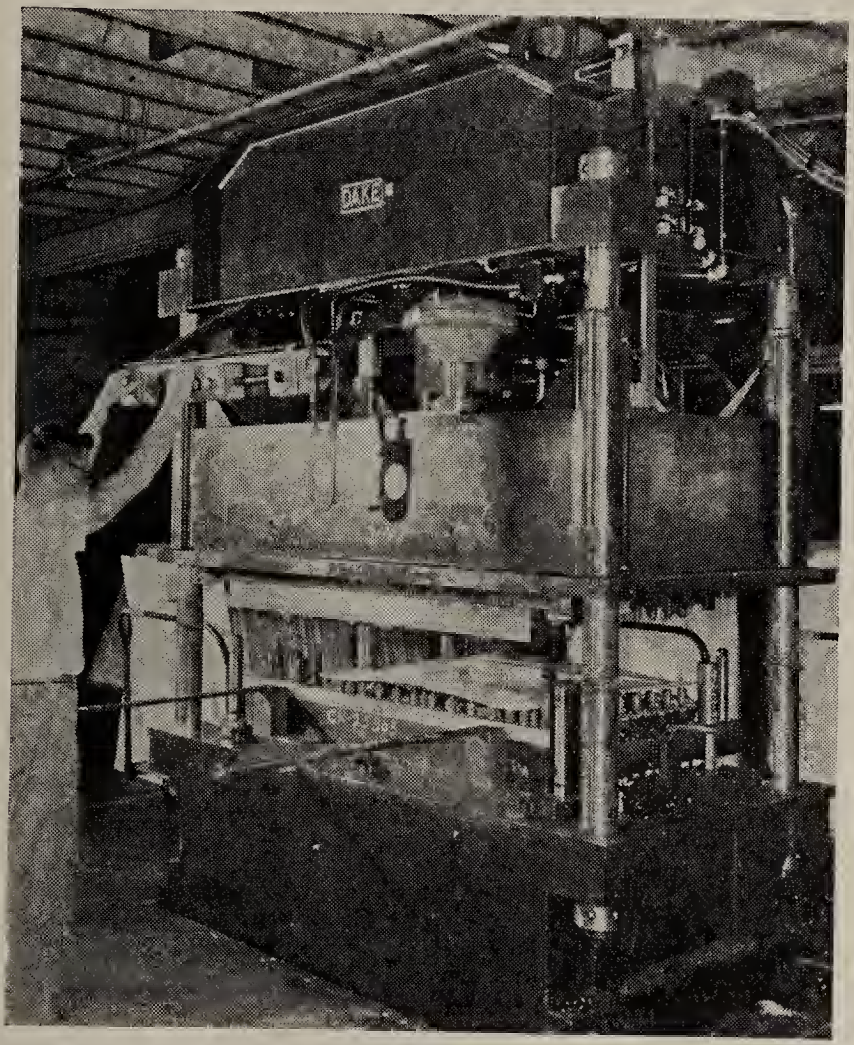

Figure 7–12. Refrigerator door liner has been placed in the trimming and perforating die and is ready for cutting. Note two-handle safety overhead arrangement for complete protection of the operator. Long stroke press permits easy loading and unloading of the die. Long guide pins on the die and the guided platen will maintain alignment of all the cutting edges. Stops on the die will prevent over-travel. (*Courtesy Dake Engine Co.; Installation, Kent Plastics*)

temperature before cutting or else the dimensions of the final part will vary. For example, if the cutting were to take place at 125 to 140° F, by the time the cut part had cooled to room temperature the mounting holes would be closer together than the die dimensions. The usual practice is to have the sheet former have six or eight parts between the cutting press and the sheet-forming machine and to always take the part which had remained there the longest.

Some people advocate this method since the parts would be slightly warm and there would be less chance of cracking while cutting. Others prefer to have a separate section utilizing one or more cutting presses. This would require more handling since the parts must be moved from the forming area. This, of course, removes the cutting from the sheet former but the increased production would offset the difference in cost.

For best results the dies are given shear in two directions so that there is no high impact at one level which would tend to shatter the plastic. A .100 inch thick plastic door liner can be cut in approximately 10 seconds, loading and unloading not included. Good production is 120 doors per hour which is considerably faster than sheet forming. Normally the capacity of one hydraulic press is equal to the output of two sheet-forming machines.

When thicknesses of plastic exceed ⅛ inch or when a horizontal cut is desired many of the above types of cutting will be impossible. Since some plastics are up to ½ inch thick, cutting is limited, and they must either be cut by saw or by routing.

Where sawing is possible, high-speed carbide inserted blades are used at fairly high speeds. Gaps are left between the teeth to give plenty of scrap clearance. Standard wood equipment such as bandsaws and circular saws are used for this purpose. Sometimes two circular saws are mounted side by side and the plastic part placed on a jig which is run between the two saws, trimming both sides at one time.

For horizontal cuts, the blades may be mounted on the spindle of a vertical router and the parts slid along at the specified height to trim the flash. Similarly, two routers may be placed adjacent to each other and two edges trimmed simultaneously.

For parts with contoured edges a hand router can be used successfully. The routing bit placed in this unit runs at extremely high speeds. The plastic is placed in a jig which has an edge contoured to the final form. The router is then started at one corner and follows the jig completely around the part until it returns to the starting point. This type of cutting is used extensively in the aircraft canopy industry and for the heavier acrylic and ABS materials. Parts may be cut out of the interior sections using this same technique.

In general, in surveying the type of cutting equipment required, the clicker and the die press are used for thinner materials; the crank press, hydraulic press, and the hot die press for medium materials; and routing for medium and heavy materials.

Parts are also stamped in standard stamping dies of the type used in the metal industry. This is especially true of extremely small light gauge parts which may be stamped on a continuous roll feed basis.

Roughly speaking, one cutting press will handle the output of two sheet-forming presses if their platen sizes are comparable.

## Mold Temperature Control Unit

Another piece of equipment which is required, in addition to the sheet-forming press, is a mold temperature control unit. This unit mixes and pumps water of the proper temperature to keep the mold at the required temperature. If the forming mold is too cold the plastic material will lock on the high parts and will stretch unevenly. If the mold is too hot then the cooling cycle becomes extremely long, reducing the output. It also is difficult to remove a part which has not sufficiently cooled since it will adhere to the mold and will deform from the stripping pressure. Proper mold temperatures for styrene copolymer are from 125 to 135° F. Cellulose acetate requires a temperature of from 145 to 155° F for proper operation of the mold.

Many machines also have water running through the clamp-

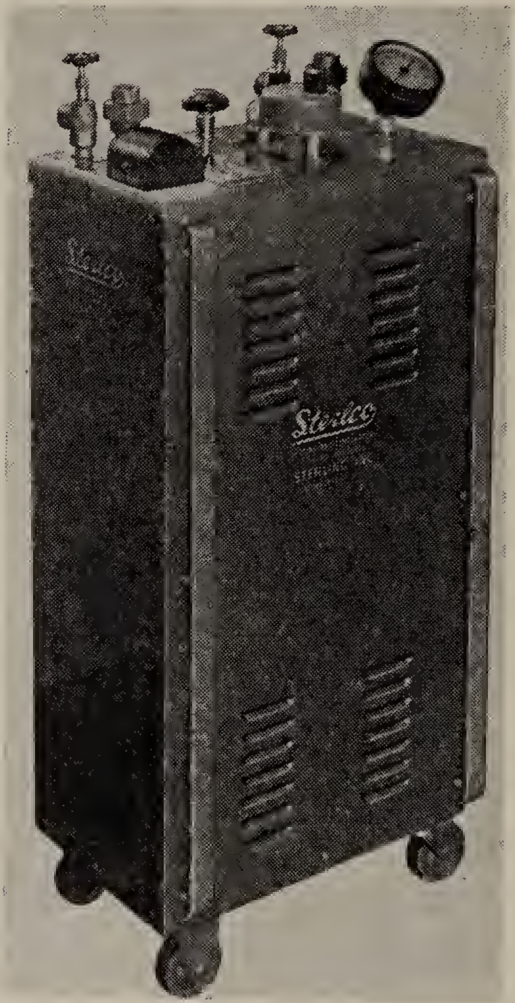

Figure 7–13. Mold temperature control unit. The above unit takes water and heats it to the proper temperature, and circulates it through molds or temperature controlled frames of a sheet-forming machine. Single unit here has only one circuit; however, a dual unit can handle both mold or frames. Automatic regulator will shut off water and operate a closed system to reduce water usage. Controller is easily set at proper temperature. Thermometer indicates exact temperature of water in circulating system at all times. (*Courtesy Sterling, Inc.*)

ing frames to prevent the metal from drawing heat from the plastic. Proper design in adjustable clamping frames always requires the cooling lines directly adjacent to the four sides of the plastic sheet. For styrene copolymer 185° F is considered acceptable for the clamping frame. In running polyethylene, temperature control is essential to keep the frames cold enough to prevent the polyethylene from becoming syrupy. When this happens the plastic will stick to the frame and it must then be opened and cleaned.

Mold temperature control units come in two types—either single, for use with a mold only, or as a dual unit for both mold and temperature controlled clamping frames. Each section has its own pump and temperature regulator and can be set as a closed system, using no external water once the system is filled. When turned on before starting production, these will insure proper die temperature, and they will maintain the temperature condition during delays, etc.

# 8. DECORATING

Sheet-formed products are among the most beautiful and most attractive of all plastic items. This is due not only to the wide range of colors, laminates, metalizing, and embossing but mainly to the ease of decorating the flat sheet prior to forming. This remarkable characteristic has resulted in the thousands of colorfully decorated, yet relatively inexpensive, plastic products which have appeared on the market in recent years.

There are, of course, many tricks of the trade used by the various sheet formers to produce unusual effects, and many plastic parts are combined with cardboard, wood or metal. The basic descriptions of the decorating processes given here can be elaborated upon by the ingenuity of the designer.

The colors of plastic sheet can be as varied as the hues of the rainbow. Some materials will have very bright colors, especially cellulose acetate and cellulose acetate butyrate; others, such as styrene copolymer, will have a lower degree of brightness and may be improved upon by laminating a thin film (.001 to .002 inch thick) of oriented styrene at the time of extrusion. Other extruders prefer to gloss the sheet by quick heating after extruding, which literally melts the surface into a glossy sheet.

Most plastic therefore has the color throughout the sheet and any scratch or blemish will not cause a noticeable discoloration. Some laminates however are produced with a random color center and only the top sheet of the desired color. This is done to reduce the cost of the sheet since scrap material may be used in the center. The top layer however is sufficiently thick so that even fairly deep scratches will not show the center color.

Graining or an embossed leatherette finish is usually furnished only on styrene copolymer or the ABS type sheet. On extruded styrene copolymer the design is embossed on the sheet directly after extrusion. Care must be taken in forming to keep the design surface on the side away from the mold and to keep the sheet temperature low so that the heat will not erase the design. On the ABS type of material the design is embossed on the top layer of the laminated sheet. It has a greater temperature resistance and therefore can be fabricated by almost any of the sheet-forming techniques without damage.

Some manufacturers furnish plastic sheet with imbedments of different color plastics or with tiny bright metallic particles. These are mixed in the hopper of the extruder and are produced in many beautiful random designs for sheet-formed products. With opaque materials, the resulting design would be a surface decoration. However, if a transparent or translucent plastic material were used, the imbedment would be visible through the sheet. Many beautiful decorative items, such as lighting shades, shower doors, and illuminated wall panels are produced this way.

The laminating together of two or more sheets by applying heat and pressure increases the selection of plastic sheet materials considerably. Sometimes a sheet is printed or designed on one side and covered with a transparent sheet to protect the design. As pointed out previously, an oriented styrene film laminated to a styrene copolymer produces a hard glossy sheet suitable for refrigerator door liners. “Mylar,” when metalized, resembles a highly polished metal. When laminated to flexible vinyl the resulting sheet is brilliantly metallic, yet flexible. It is used extensively for automotive interior trim where it can be easily heat sealed and joined to other components.

A recent innovation in plastic sheet is the development of printed wood grains which can be retained throughout the forming process. Especially valuable in counter displays, office equipment, picture frames, and similar items, it offers simulated wood finishes which rival actual wood products. Graining has been mainly used on styrene copolymer sheets, but it may be applied to any plastic sheet which can be printed.

Flocking is a method of producing a short nap, resembling fabric, on any surface. This velvet type of decoration is used on plastic sheet to form jewelry cases, tool display cases, fine silver displays and similar products. Used mainly with styrene copolymer, the products are formed to good depths without exhibiting a color change due to the plastic thickness change. For best results, the plastic sheet is an opaque color, slightly darker than the color of the flock.

Metalizing is by far one of the easiest ways to duplicate a metallic product using plastic sheet. Products such as three-dimensional displays, trims and borders on picture frames and radios, placques and medallions resemble metal or heavy products to a point where they cannot be distinguished from the original without close examination. Cellulose acetate and cellulose acetate butyrate are the two most popular materials for metalizing. The metallic coating is applied on one side only. When heating, the metallic coating must be on the side away from the heater so that the heat can penetrate the plastic and not be reflected away from it. When designing, it is best to have the metallic surface on the inside of the product. Thus the outside plastic will protect the metalizing from scratches or stains and will keep the product brilliant.

Only the decorative effects which are purchased as part of the plastic sheet have been discussed here. When we study the art of pre-decoration, which is applying a distorted pattern to a flat sheet and forming it into a product on which the color is registered. There are many tricks of the trade in which a good schooling is essential.

To obtain good register in the colors of sheet-formed parts, the following basic rules should be followed:

1. Use good equipment. Machines with erratic timing, nonuniform heaters, and varying cycles will present insurmountable obstacles to pre-decorated products.

2. Test the mold before trying to register your plastic sheet. Work out the forming cycle, cooling cycle, sheet thickness, drape assists, and remove undercuts and defects from the mold.

3. Select your material supplier before determining your distortion pattern. If possible, use sheets from the production run for distortion tests. Always keep the sheets in the same relationship to the mold, i.e., direction of calendering should always be front-to-back or right-to-left to keep variations to a minimum. This also applies to direction of extrusion. Most manufacturers will mark the sheets so that proper orientation can be maintained. Avoid square sheets. Use rectangular sheets wherever possible to avoid spoilage. Square sheets may be wrongly fitted into screens, printing presses, and forming equipment.

4. Use inks and paints which have been tested for stretch and durability. It is important that these be of the highest quality obtainable.

5. Inform your plastic supplier that you intend to predecorate the sheet, and which process you plan to use. He can then furnish sheets with special surface treatments which will ease your problems. Remember, if printing equipment is used, the sheets must be accurately squared or they will not feed properly. Silk-screening usually does not require this accuracy.

6. Use the same drape speed, heater temperature, and operating conditions during the production run as used in determining the distortion pattern. Be sure that the molds and clamp frames are at the correct temperature during pre-decoration testing.

7. Remember, colors will change when stretched. If a sec-

tion of a part stretches excessively the color may change considerably. Since the colors tend to lighten slightly, darker colors should be used.

Several different methods may be used to arrive at a distortion pattern. One method involves forming a plastic sheet over the mold after all the above points have been observed. The forming is done in a slightly shorter time than the determined cycle so that the part will not adhere to the mold. The part now resembles the final product, without the decoration. The product is then decorated by spraying each section with a small air brush using the final ink colors. Be careful to use a very thin spray. Some people prefer to determine the color registration by merely penciling in an outline of the colors on the formed piece. In many cases this is sufficient to cut the silk-screen pattern or to make the printing plates.

The plastic sheet now undergoes a curious phenomenon. If heated, it will unform completely and return to a perfectly flat sheet. This property, known as "elastic memory," is very accurate. The decorated formed part is returned to the clamp frame of the machine, reclamped and reheated. The formed part will unform, the thin sections will thicken, and the colored or outlined sections will grow smaller. Straight lines will curve, letters will reduce, and the final pattern on the flattened sheet is ready for cutting silk-screens or for making printing plates. Not only does this remarkable trait hold true in unforming, but in forming this flat pattern can be returned exactly to the formed pattern.

Another popular method of determining registration of designs is by making the original forming on a sheet which has been graphed with horizontal and vertical patterns. With a ⅛-inch square, appropriately identified, a skilled person can plot any outline to another plotted sheet and thereby develop the distortion pattern without unforming the plastic product. This method also has an advantage in that it will reveal thin sections. The ⅛-inch squares are directly related to the thickness. If in any spot the ⅛-inch square becomes a ¼-inch square, then the thickness at that spot would be 50 per cent of the original thickness.

Having determined the distortion pattern, silk screens may be cut or photographed from the master. Standard silk-screening techniques are used with the sheet-forming paints. The paints themselves will stretch with the plastic without cracking or loosening. When printing, greater care must be employed. The sheets must have perfectly square corners and the surface finishes should be specially ordered. The inks in general are thinner and special printing plates must be made for this process. Sometimes, double printing is required. Printing inks also have less adhesion to the plastic sheet, thus greater care must be taken to prevent scratching.

One of the best materials for accurate pre-printing is calendered vinyl sheet. Because of the calendering process the surface of the sheet is slightly rough, and it is therefore usually printed by rotogravure or lithography. This surface does not affect silk-screening. Cellulose acetate and cellulose acetate butyrate may be printed by the direct process as well as by lithography or silk screening.

Any of the above methods of pre-decoration may be used on styrene copolymer but extreme care must be taken to order marked material which indicates the direction of extrusion and the sheet edge. This insures that the plastic sheet will respond uniformly to heat and to the forming technique.

Plastic sheet-formed products may be decorated after forming by conventional methods. Sometimes, accurate lettering, which is difficult to register by pre-decoration, is omitted. If these letters are on the same level they may be simply roller coated after forming. For contoured designs or tonal effects, spraying may be used. In this case masks are used to protect the product or to establish the painted pattern. Some manufacturers use the same molds to make paint masks of a thicker and different plastic material. After cutting out the proper sections, these masks can be used for a considerable number of pieces before they have to be discarded.

Contoured silk-screening may also be used to decorate formed parts. This is more difficult and requires greater skill than some of the other methods.

Combinations of pre-printing, pre-silk screening, and roller coating after forming are common. Silk screening is used on the solid colors, printing for halftones and delicate shading, and roller coating for lettering. Products requiring fine shades and tones are printed. Colors in pre-printing or pre-silk screening may be solids where each one is the exact final color, or they may be transparents where two colors may be printed at the same section to form a third color, exactly as printing is done on paper. Many signs and displays employ transparent colors with excellent results. The color, when viewed unilluminated and when viewed illuminated, may be different and adjustments must be made in the paint or ink to obtain the desired results.

Costs of pre-decorating are far less than for decorating a formed product. This gives the sheet-formed products a definite cost edge on products produced by other methods. Pre-decorating has opened a whole new field to colorful plastic products. Sheet forming alone has an exclusive in the field of colorful plastic products.

# 9. PRODUCTION COSTS

One of the first questions asked of a sheet former is, "How much will it cost?". Like many other new processes the data for estimating costs must be evaluated to arrive at an accurate figure or else the production run will fail to show a profit.

The sheet forming process appeared so simple that some people automatically thought of it as a cheap process, and in buying parts they forced low prices on the sheet formers new to the industry, and consequently the results were disastrous to both. With the growth of the industry now approaching its fifth year, this condition has fairly well disappeared due to the greater experience of the sheet formers in estimating costs and to the realization by the buyers that poor quality parts are expensive. Some of the parts produced by sheet forming are the most expensive of all the plastic industry. For example, the aircraft canopies and large gasoline signs cost as much as several hundred dollars each! It must be remembered that plastic sheet is not inexpensive, but costs from $.50 to $1.75 per pound. However sheet forming enables extremely thin materials to be formed into acceptable products. With the large platens and the fast cycles of the newer sheet-forming machines, the labor cost may be very small in relation to the material cost. In many cases it may be as little as 5 to 10 per cent of the material cost. Thus, if costs are to be kept at a minimum one must give considerable thought to the way in which the plastic is going to be used. In some cases merely by reducing the clamping edge from 1 to ½ inch a savings can be effected equal to the labor charge for sheet forming the product.

The scrap factor should also be considered in sheet forming. Since sheet forming uses square or rectangular sheets, a round part would have the greatest amount of scrap. Some products may have a scrap loss as high as 40 per cent.

The factors to be considered in estimating the cost of the product are as follows:

A. Design factors
    1. Type of equipment
    2. Total production run
    3. Mold cost and die cutter cost
    4. Set-up time
    5. Mold and cutter repair and maintenance

B. Production factors
    1. Material cost
    2. Spoilage
    3. Scrap
    4. Sheet forming cost
    5. Die cutting cost
    6. Cost of operating sheet former and auxillary equipment

C. Overhead costs

### Design Factors

In examining a product for manufacture and in estimating its cost, the first consideration is the type of equipment available. The size of the equipment is of primary importance. For example, suppose a company has two machines, with platen dimensions of 24 × 36 inches and 30 × 50 inches. If a part 12 × 30 inches is contemplated, the smaller machine would have a maximum yield of 2 per cycle and the larger machine a maximum yield of 4 per cycle. The cycle time of the larger machine would be only approximately 10 per cent more than that of the smaller one. Machines with completely automatic cycles, such as a "Roll-Vac," may have a smaller platen but they will produce parts considerably faster than a hand-fed machine.

Such features as controlled air blow-off, automatic operation after clamping, high temperature heating, fan cooling, heater temperature controls for maintenance of the same cycle times, temperature controlled molds and frames are all necessary to give a uniform consistent production output. If any of these go out of control during a production run it means that the operator must constantly inspect the product to see if the heating cycle must be lengthened or shortened, the cooling time changed, or air blow-off adjusted to give proper release. This means that production is erratic and that the output will fail to meet estimates. A good source of electricity and a good air and vacuum system are necessary so that the operator will not have to cease production until heat, air or vacuum regains its proper intensity.

The total production runs must be carefully considered to determine the following:

1. The size of the mold or the number of parts to be made at one time.
2. The type of mold construction such as wood, plaster, plastic or metal to last through the production run.
3. The total poundage of material to be used so that the minimum cost per pound can be obtained.
4. The use of temperature controlled molds.
5. The selection of the die cutter or the method of cutting.

The production run may be small in the order of a few hundred pieces or it may be in the order of several million. Both runs may be made on the same machine, with only the die components varying.

The selection of the mold and cutter depends on many factors. First, as mentioned in Chapter 5 the proper mold material depends on the type of product, the type of material, and the production requirement. Then, keeping in mind the basic sizes and widths of the plastic material to be used, a cost analysis should be made based on two or three mold sizes and their production outputs, and finally, these figures should be evaluated to produce the lowest piece part price.

Mold charges are usually not a profit-making item and are often passed on to the customer at cost. If the mold cost is large and the production run small, a considerable amount of money and time may be spent with no profit. The estimates of mold cost are given in Chapter 5 but by no means do they represent the total mold charge. Original designs or sculpturing, original set-up and testing, preparation of test samples from the mold, transportation to and from the moldmakers and other items are not included in the estimates, all of which add up to a considerable amount of money which must be recovered.

Die-cutting costs are more readily available if a sample sheet from the completed mold is submitted to the diemaker for matching. With this to work from accurate dies can be made. However since the mold is already in production before such a sheet can be obtained the need for the die cutter is always urgent and it may cost more for quick delivery.

The set-up time for sheet forming may be very slight in most cases, but it may result in a considerable charge for some of the more complicated methods. The better the controls are for the auxiliary and sheet-forming equipment, the less the cost of set-up. Obviously, if the mold can be precisely heated, the temperature of the frames controlled, and the various cycles pinpointed, the easier it will be to set-up and duplicate the production cycle of any sheet-formed part.

One manufacturer uses several molds to produce plastic parts ordered in small quantities, but the orders are repeated every month. By making all molds the same size, and by using roll stock of the same width, he can change a mold and resume production in less than five minutes.

Maintenance of molds and cutters is usually not a costly item, except when the mold selected is not correct for the production quantity and speed. For example, if a wood mold is used too long or allowed to operate at too high a temperature it would require frequent repairs.

## Production Factors

In calculating the cost and usage of any plastic material one will be confronted with the fact that suppliers will list their materials differently. Some will give costs in pounds of material, some in costs per square foot, some in costs per roll, and some in costs per 1000 square inches. Most products are measured in inches, thus a figure based on the cost per 1000 square inches can be most readily used. For example, suppose 1000 square inches of a plastic material cost $1.00, and each sheet had to measure 20 × 20 inches. Each sheet then would contain 400 square inches and would cost $.40.

To convert the known data to cost per 1000 square inches is not difficult. All plastic charts give the specific gravity of the material.

To find the weight of 1000 square inches of material the following formula can be used:

$$\text{Weight in lb/1000 sq in.} = \text{specific gravity} \times 36.4 \times \text{thickness in thousandths.}$$

For example, cellulose acetate has a specific gravity from 1.28 to 1.34 (check with your supplier for the exact figure for your specific formulation). Using 1.32 as an average and a thickness of .005 inch, the weight of 1000 square inches would be

Table 9–1. Standard Sheet-Forming Materials
Specific Gravity and Thickness Range

| Material | Specific Gravity | Thickness Range |
|---|---|---|
| *Acetates* | | |
| Cellulose acetate, extruded and cast | 1.28–1.34 | .0005 – .250 |
| Cellulose acetate butyrate, extruded and cast | 1.15–1.25 | .0007 – .250 |
| *Vinyls* | | |
| Flexible vinyl, calendered | 1.23–1.42 | .004 – .040 |
| Flexible vinyl, cast film | 1.23–1.30 | .002 – .008 |
| Vinyl copolymer, calendered | 1.35–1.45 | .002 – .040 |
| Vinyl copolymer, press polished and laminated | 1.35–1.45 | .002 – .250 |
| Polyvinyl chloride, extruded | 1.35–1.56 | .010 – .030 |
| Polyvinyl chloride, calendered and laminated | 1.35–1.56 | .015 – .500 |
| *Styrenes* | | |
| Polystyrene copolymer | 1.04–1.06 | .005 – .250 |
| Straight polystyrene | 1.05–1.07 | .040 – .125 |
| Oriented polystyrene | 1.05–1.07 | .001 – .020 |
| *Styrene Blend* | | |
| Copolymer acrylonitrile-styrene, extruded | 1.05–1.07 | .030 – .187 |
| Copolymer acrylonitrile-butadiene-styrene, calendered | 1.05–1.24 | .010 –1.000 |
| *Polyethylene* | | |
| Standard polyethylene | .925–.94 | .001 – .373 |
| Low pressure or linear polyethylene | .935–.96 | .001 – .373 |
| *Acrylics* | | |
| Cast acrylic | 1.18–1.22 | .060 –3.00 |
| Extruded acrylic | 1.18–1.19 | .040 –1.25 |
| Oriented acrylic | 1.18–1.19 | .015 – .020 |
| *Specials* | | |
| "Mylar" | 1.38–1.39 | .00025 –.0075 |
| Cellulose nitrate | 1.35–1.60 | .003 –3.00 |

$$\text{Wt.} = 1.32 \times 36.4 \times .005$$
$$\text{Wt.} = .24 \text{ pounds per 1000 sq in.}$$

Thus .005 inch cellulose acetate would weigh approximately ¼ pound per 1000 square inches. If the quantity which you are buying brings the price to 80¢ per pound, then each sheet would cost .192¢.

If you could obtain 10 parts per 1000 square inches then each part would cost 1.9¢.

To determine your material cost, first make a layout of the parts to be formed to get the best advantage of your machine, the production required, the best forming technique and the limits of your cutting equipment. Now figure the dimension of the clamping edge. This is usually 1 inch but with good operating conditions it may be reduced to ½ inch. Add this to the mold dimensions to obtain the final sheet size. Check this against your supplier's list to see if it is a standard dimension, as odd sizes may require a premium cost. For example, cellulose acetate of one supplier may come in widths of 22, 31 and 44 inches. Rolls may be cut to smaller widths but, for example, a 23-inch width would have an 8 inch waste when cut from a 31 inch standard roll. Thus by changing the mold layout to use a 22 inch standard width material a considerable amount of money may be saved. Sizes however vary from supplier to supplier and the policy of each company differs. Some companies will supply cut sheets of any size at no added cost.

Now, having determined the final sheet size to be used and the weight of each sheet, costs may be figured, depending on the production run. Usually, the minimum cost is at the 20,000 pound level, but it may be as low as 500 pounds on standard stock material. Each supplier must be checked for quantity prices. Now, with the sheet size and the weight per 1000 square inches and the quantity price, the cost per sheet can be determined.

TABLE 9–2. APPROXIMATE PLASTIC MATERIAL COST
(January 1957)

| | Cost per 1000 sq inches | | |
|---|---|---|---|
| Material thickness . . . . | .010 | .030 | .060 |
| Cellulose acetate | $.39 | $1.10 | $2.20 |
| Cellulose acetate butyrate | .44 | 1.32 | 2.64 |
| Flexible vinyl | .24 | .69 | — |
| Vinyl copolymer | .34 | .68 | — |
| Vinyl copolymer, press polished | .67 | 1.32 | 2.64 |
| Polyvinyl chloride, calendered | — | 2.03 | 3.71 |
| Polystyrene copolymer | .24 | .61 | 1.22 |
| Straight polystyrene | — | .64 | 1.28 |
| Oriented polystyrene | .27 | — | — |
| Styrene blend, extruded | — | 1.02 | 2.04 |
| Styrene blend, calendered | — | 1.47 | 2.73 |
| Standard polyethylene | .27 | .65 | 1.30 |
| Low-Pressure or linear polyethylene | — | .79 | 1.58 |
| Cast acrylic | — | — | 4.20 |
| Extruded acrylic | — | — | 2.59 |
| Oriented acrylic | .67 | — | — |

| | Cost per 1000 sq in. | |
|---|---|---|
| Thin material . . . . | .003 in. thick | .005 in. thick |
| Flexible vinyl, cast | $.135 | $.23 |
| "Mylar" | .34 | .56 |

Where no figure is shown, the thickness or cost may not be available at this time.

The above are minimum costs based on maximum poundage. It may be from 500 to 20,000 pounds of one color, or other special conditions as dictated by the plastic suppliers. Check your suppliers for final data on all pricing conditions.

For example, suppose we wish to run 1000 pieces of a part of styrene copolymer .060 inch thick, two at a time, from a sheet 20 × 30 inches.

The specific gravity is 1.05.

$$\begin{aligned} \text{Wt. per 1000 sq in.} &= 1.05 \times 36.4 \times .060 \\ &= 2.3 \text{ pounds} \end{aligned}$$

Since each 20 × 30 inch sheet would make two parts, only 2500 sheets would be required, and each sheet would weigh

$$\frac{600}{1000} \times 2.3 = 1.38 \text{ pounds}$$

Total order—2500 sheets @ 1.38# = 3450#

The cost of the material is:

| | |
|---|---|
| 1000–1999 pounds | 61¢ per pound |
| 2000–5999 " | 57¢ " " |
| 6000–9999 " | 54¢ " " |
| 10,000–19,999 " | 53¢ " " |
| 20,000 and up " | 52¢ " " |

In checking the above list we see that the price would be 57¢ per pound for a 3450 pound order. Each sheet would be 1.38 × .57 or \$.786. The material cost of each part therefore would be .786 ÷ 2 or 39.3¢.

## Tolerance

Another factor which should be checked is the tolerance of the plastic sheet. For example, an extruded styrene copolymer sheet .010 inch thick may have a thickness tolerance of ±.0015 inch. If ordered by the pound one might obtain a quantity of sheets within ±15 per cent of the required amount. For example, suppose the size of a .010 inch thick sheet were such that is weighed 1 pound and 1000 parts were required. If 1000 pounds were ordered, one could obtain from 850 to 1150 sheets. To prevent this variation some sheet formers would order the material by the sheet instead of by the pound. The cost however would still be on a per pound basis. This, too, presents a problem if the cost has been figured at .010 inch and the material is .0115 inch thick when received. This would result in a 15 per cent increase in material cost. A proper understanding of how plastic sheet is manufactured is a “must” for accurate pricing of products.

Spoilage is another item which can be quite costly, especially if the part has been pre-decorated. Again, the better the production equipment, the less will be the spoilage. One manufacturer recently made a production run of 6500 pre-decorated displays, 30 × 12 inches, with six colors. Despite the fact that close registration was required only twelve parts were lost in this production run of over 100 hours. On the other hand, some companies have complained of high spoilage and have objected to paying for better molds, temperature controls, and better equipment. A low spoilage loss depends completely on the operational set-up and should never exceed 1 to 2 per cent.

Scrap material from the trimmed clamping edges and from between molds has value, if it is clean. It may be sold to scrap dealers who re-grind and re-process it. Its value fluctuates considerably; it is usually under 15¢ per pound for styrene copolymer. Some materials may be sold back to the original supplier under certain agreements; other materials have no value. Before including this item as part of your cost figure, remember that if you must retain the material due to a change in scrap price, a considerable amount of valuable floor space may be lost.

The cost of sheet forming can vary widely but it can be figured quite accurately for various types and sizes of machines. By far the most common machine in use at the present time is the general-purpose combination drape and straight vacuum machine. For various sizes of these machines, from 6 to 25 square feet, the heating and cooling time depend only on the thickness of the plastic and not on the size of the machine. Larger machines have slower operational times but are not greatly different from the small machines. For example, the output of a general-purpose machine for .100 inch thick styrene copolymer would be as follows:

| 6 sq ft machine | 12 sq ft machine | 24 sq ft machine |
|---|---|---|
| 34 to 52 parts/hr | 30 to 47 parts/hr | 28 to 45 parts/hr |

For a 6 square foot general-purpose machine the average output rates would be as follows:

Cellulose acetate .010 in. thick
From 70 to 130 cycles/hr

Calendered vinyl .010 in. thick
From 90 to 160 cycles/hr

The reasons for the wide variance in output are many, as pointed out earlier. The type of machine, the mold, the auxillary equipment, and the product design are all contributing factors in determining the production rate. The production cycle is made up of the following components for a general-purpose combination drape and straight vacuum machine:

| | |
|---|---|
| Machine time<br>Clamp and unclamp<br>Heater forward and reverse<br>Drape down and up<br>Air blow-off | Average from 6 to 15 sec. |
| Heating time | Average from .25 sec. per .001 in. of thickness for styrene copolymer up to 1 sec. per .001 in. of thickness. |
| Cooling time | Depends on material—from ½ to equal of heating time. |
| Loading and unloading time | 10 to 15 sec. |

Thus, from the above one can figure the cycle time as loading and machine time plus heating time plus cooling time.

Die cutting production can generally be figured as being two to three times as fast as sheet forming. The actual time of cutting is short, averaging from 1 to 10 seconds per cut, so that the greatest amount of time is used in handling or loading and unloading the press. The number cut per cycle, the weight of the die if it has to be lifted, the product design, the method of cutting, and the type of cutting press all contribute to the cutting cost. Most thin materials can be stacked so that several thicknesses can be cut at one time.

The cost of running a sheet-forming machine may be considerable in some areas due to the high cost of electricity. Most heaters are controlled by on-off temperature regulators so that power is used only 50 per cent of the time. Since watt densities of the heater vary from 1 to 3 kw per square foot, costs will vary based on a 3.5¢ per kwh from 1¾¢ to 5¢ per square foot. For example, a typical 30 × 50 inch machine would cost about 35¢ per hour to operate.

## Sample Cost Estimate

A typical cost estimate for a product could be handled in the following way:

| | |
|---|---|
| Type of machine | 30 × 50 general-purpose machine |
| Material | .010 in. thick cellulose acetate |
| Size of part | 15 × 18 in. without clamp edge |
| Size of order | 20,000 parts |
| Mold selection | Epoxy with aluminum filler |

To determine the minimum cost of this product one must determine how many should be made at each cycle and the cost per unit for each different possibility.

| Number of parts per mold | 1 | 2 | 3 |
|---|---|---|---|
| Size of mold (estimate) | 18 × 15 | 18 × 30 | 18 × 45 |
| Size of plastic sheet | 20 × 17 | 20 × 32 | 20 × 47 |
| Square inches per sheet | 340 | 640 | 940 |
| Mold cost | $200 | $400 | $600 |
| Cutter cost | $100 | $175 | $250 |
| Material cost - - - @ .39 per 1000 sq in. (See Table 9–2) | | | |
| Sheet cost | 13.3¢ | 24.9¢ | 36.6¢ |
| Unit cost | 13.3¢ | 12.5¢ | 12.2¢ |
| Cycles per hour | 120 | 108 | 98 |
| Parts per hour | 120 | 216 | 294 |
| Hours for 20,000 pcs. | 166.7 | 92.4 | 68 |

Using the above figures we can make a total cost of the entire run of 20,000 parts based on using a mold of 1, 2 or 3 parts and a cutting die to match. The total cost for the run is then divided by 20,000 to give the cost per part. The lowest piece part cost will determine which way the part should be run. It must be kept in mind that we have used only estimates for the mold cost and cutter die cost and should the part be complex these may appreciably alter the results.

### COST SUMMARY

| Parts per mold | 1 | 2 | 3 |
|---|---|---|---|
| Material | $2660.00 | $2500.00 | $2440.00 |
| Waste allowance, 2% | 53.00 | 50.00 | 48.00 |
| Forming cost, $1.50/hr. | 250.00 | 138.60 | 102.00 |
| Cutting cost (½ forming) | 125.00 | 69.30 | 51.00 |
| Overhead, 100% | 375.00 | 207.90 | 153.00 |
| Mold cost | 200.00 | 400.00 | 600.00 |
| Cutter cost | 100.00 | 175.00 | 250.00 |
| Set-up cost | 50.00 | 60.00 | 75.00 |
| Electrical charge, @ 35¢/hr | 58.33 | 32.34 | 23.80 |
| Total cost | $3871.33 | $3633.14 | $3742.80 |
| Unit cost | 19.35¢ | 18.16¢ | 18.71¢ |

From the above it can be seen that the lowest unit price for this product would be 18.16¢ each, based on a run of 20,000 parts, using a 2 up-mold and cutting two parts at one time.

# 10. PROSPECTS FOR THE FUTURE

While sheet forming of plastics has been in existence for many years, it is only since 1952 that the field began expanding. In these few years its volume of products has grown to a point where last year the industry consumed an estimated 85 million pounds of sheet-formed plastics. It has been estimated that by 1965 over 200 million pounds of plastic will be expended annually for sheet-formed products.

Unlike many other fields, new products can be developed quickly and inexpensively due to the low tooling costs. With only a simple wood mold, made in a few hours, a sample of the proposed product can be produced. When this sample is analyzed, and cost estimates arrived at, the market value and sales potential can be determined. Using simple tools, several hundred market samples can be produced and a market testing program undertaken. If the results are favorable, production can be started, usually within several weeks, since the tooling costs are low and tooling time short, as compared to other industries. The risks are low and the expense moderate so that any company need not fear to develop new products. This alone indicates that many more new products can be considered using sheet forming than in any other industry.

In what direction will the new products be developed? In the previous application listing, many fields were shown, each of which is developing new products daily.

In the appliance field the use of sheet-formed parts has increased considerably. The most notable, of course, is the refrigerator door liner which has grown more intricate year by year. In Europe where refrigerators are small, the interior of the box has been produced in good quantity. The portable radio cases of ABS material now produced in quantity here have given the industry a shock-resistant product superior to plastics produced by other methods. Scale housings and Coco-Cola dispensers consisting of several parts are good examples of sheet forming. Parts of washing machines, television sets, kitchen dispensers, drain boards, and sewing trays are but a few of the items now on the market. With its unique decorative ability, many appealing products can be sheet-formed to fit the decor of modern living. The plastic conscious public demands new and novel applications and sheet forming has the answer.

Automotive applications are on the increase. Plastic offers many advantages—the excellent colors, the fabric-type finishes, and the ease of production of complex curves and contours provide the stylist with a new modern tool. Sheet-formed parts for automobiles reduce labor, and consequently costs, since both the decorative and utilitarian aim may be produced at one cycle of the forming press. Door panels, instrument safety pads, sun visors, seat kick pads, cover struts, glove compartments, rear deck covers, and roof interiors, have already been produced in quantity. Entire seats, formed floor covers, trunk compartment liners, and arm rests are currently undergoing tests or are being tooled for production. Not only pleasure cars but station wagons, panel trucks, and cabs of large tractor trucks already have parts made by sheet forming.

Don't forget packaging of spare parts. Kits containing a condenser, points, rotor and small parts, packaged in a transparent cover on a card provide a ready answer to distributor troubles of the car owner. All types of spare parts, from gaskets to gears, can use this protective transparent plastic package which offers a quick check of its contents. Estimates of 8 million pounds of material used by the industry in 1956 is only a small fraction of the amount the automotive field expects to use in the next few years.

For many years luggage manufacturers used vinyl sheet which was cut and cemented to wood forms. Now luggage, as well as portfolios and brief cases, consists of a shell formed entirely of styrene copolymer or of sheeting molded over a cellulose fiber contour core. With predictions that in a few years most of women's luggage and a good part of men's luggage will be made of plastic, sheet forming will play an important part in this field.

Modern lighting panels have made great strides since their introduction a few short years ago. Sheet-formed ceiling and fluorescent light pans will be further developed into units for the home as well as for the office. Beautiful patterns, such as the basket weave patterns of acrylic, have been used to create startling wall and ceiling illumination beyond our imagination of several years ago. Translucent, transparent, embossed and imbeded designs create effects which will be used by our lighting engineers in the coming years. Improved formulations to meet these requirements are available from nearly every major supplier. One major lighting house indicated that nearly 75 per cent of its total business was in plastic diffusers and ceilings. Combinations of plastics in various colors with metallic inserts or bars have been used effectively on some ceilings.

Transportation, such as railroads and airplanes, has long recognized the value of plastics. The low tooling cost of sheet forming has made plastics a natural for passenger cars and aircraft. Wall panels, lighting, hat racks, seat sides, doors and covers are now being manufactured. Other parts are being studied for conversion since the beauty and durability of the sheet-formed parts have indicated a substantial saving.

Signs and displays were one of the first fields to use sheet forming, especially for pre-decorated products. Their use has expanded to a point where there are many companies who specialize in this field alone. Tiny parts, to parts many feet in dimension, are constantly in the public eye. More and more the demand is away from old materials and toward sheet-formed plastics. Practically every major display house is in the plastic business to some degree.

Signs and displays using several different sheet-formed parts are now available. They show the ingenuity of the sheet former to take advantage of the best properties of the materials. Majestic Creations, Woodside, N.Y., produces an illuminated display having transparent vinyl with rear decorations for one part, translucent vinyl which has been lithographed into a beautiful four-color insert, and a silk-screened frame section. Outdoor illuminated signs of acetate butyrate have created a new market in economy displays, yet with excellent weathering properties. The new displays have better colors, better rigidity, as well as complete approval of the advertising industry. Counter displays of medium to heavy styrene copolymer with either colored or decorative wood-grain finishes have made tremendous strides in the past year. Large display racks for packages to complete displays with the parts in place and clear transparent plastic covers are in demand from the merchandisers. Displays of cosmetics, hardwares, school supplies, women's lingerie, drugs, and many other items now appear on the store counters. One company has a line of sign backs sheet-formed with a novel ribbed construction to hold plastic letters. These modern clean-cut display signs have replaced the old departmental and advertising signs in many of the stores.

The recent advances in pressure-forming machinery permit the production of signs and displays in sharp relief and detail. Sharp formings of materials, including thick acrylic, have created new effects. Such developments are expected to expand the potentials of the display field.

The toy industry already has many sheet-formed products and others are being developed. New on the scene are airplane kits in which all of the parts are formed out of one sheet and die cut, with the parts left in place to be removed by the purchaser and a complete table-size railroad scene with bridges, crossings, and buildings, all decorated in many colors, ready for the tracks and trains.

Housewares continue to provide the high volume production for the sheet former. Low-cost disposable dishes for restaurants, such as ice cream dishes, will lead the way a complete line of disposable tableware for picnics, beach use, and the home. Decorative containers, trays, and dishes are made by laminating a reverse printed transparent overlay to a styrene copolymer sheet and then forming. Sheet-formed drawers have made an entry in the furniture field. Formed styrene copolymer furniture components are being tested to achieve the contours required in modern design. With the wood-grain finishes presently available, furniture and household items not possible with standard construction now show promise.

By far the largest user of sheet-formed plastics is the packaging industry. As pointed out previously, the basic emphasis in retail selling is centered on self-service, and there is need for visual packaging to protect the product and to create impulse buying. The types of packages are many and varied. Items in the low-cost field, previously packaged in bulk, are now individually packaged where the cost of the package is more than the product. Carded merchandise has increased tremendously. In every phase of the selling industry, from 15¢ items to items selling for more than $100.00, sheet-formed packages are being used. Complete tool kits with transparent lids, camera inserts and covers, cosmetics, automotive supplies, garden supplies, foods, and household items are just a few. Toy packaging has advanced rapidly. The latest is the packaging of sets of toy soldiers, or the like, between two sheets of clear plastic so that the entire set can be examined.

The sheet former already has an excellent choice of materials, yet new materials are being tested every day. Data on new materials are trade secrets of the plastic material companies so that information is vague. Information on costs, properties, and the availability of such materials cannot be obtained. However the plastic material suppliers are shaping their needs to meet the requirements of the sheet forming industry. Some of the current research is as follows:

1. A lower cost, easily formable transparent packaging material. Today, cellulose acetate is the most widely used packaging material. It is fairly easily formed and die cut. Oriented styrene, which costs less, is difficult to form and die cut. Developments in this field will reach a ready market.
2. Materials such as the ABS types are tough, durable, and colorful, however their high price, as compared to styrene copolymer, has not made it possible for them to reach the mass market. A styrene copolymer with higher impact will find a ready market for new products.
3. Improvements in the deep-drawing characteristics of plastic sheet material will benefit the entire industry. This means that less thinning will take place on deep draws, resulting in stronger products, or that thinner starting thicknesses will be possible.
4. A good transparent material for food will permit such products as cut meats to retain their freshness during shipment and while on display.

Special formulations to meet the demands of the sheet former are common with many material suppliers. The range of possibilities is large and the sheet forming industry can look forward to a continued improvement in the materials.

Machinery suppliers continue to offer new equipment, both faster and more automatic than the models previously available. Also, new techniques of forming sheet plastics have been developed. Improvement in deep drawing, higher detail formations, and more automation are the aims of the industry. The change from vacuum to air pressures requires further study. Vacuum machines are far simpler and cost less for most applications. Air-pressure equipment can handle hard to form materials and can make difficult formations, but it is more expensive to purchase and tool.

Approximately 400 machines were manufactured in 1956 representing an increase of 100 over 1955. An estimate of 1500 machines in operation at the end of 1956 is a good indication of the growth of this industry which, it is estimated, had less than 200 machines in 1952. Compared to the injection-molding field, which is the closest plastic fabricating industry, the rate of expansion is greater. A total of 11,500 injection molding machines is estimated for an industry which started in the middle 1930's and which added 800 units in 1956. Sheet forming shows promise of achieving an equally important status in the plastics field. New products, new materials, and new equipment will combine to create an important industry for better living.

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